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DESIGN AND INSTRUMENTATION OF AN EARTH SHOCK TUBE

Final Report

By

Atlantic Research Corporation
A Division of The Susquehanna Corporation

February 1968

Submitted to

The United States Army
Ballistics Research Laboratory
Aberdeen Proving Ground
Maryland

Contracts

DA-36-034-509-ORD-3116RD
DA-18-001-AMC-877(X)

ATLANTIC RESEARCH

216

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ABSTRACT

This report, which is divided into two parts, covers the work done under Contracts DA-36-034-509-ORD-3116RD and DA-18-001-AMC-877(X).

The major objective of this work was to design an instrumented earth shock tube for one dimensional wave propagation studies. Ideally, in a shock tube the lateral strains imposed when the load is applied should not interfere with the axial motion of the soil particles. However, the frictional effects at the walls of the confining tube are so great that the ideal situation is difficult to achieve. Therefore, an attempt was made to reduce these frictional effects by placing Teflon powder between the soil sample and the confining tube. Testing of this system indicated that imbedded stress gage behavior should be investigated before continuing further testing of the earth shock tube. Therefore, two laboratory devices, the dynamic oedometer and the dynamic triaxial apparatus, were designed for investigating imbedded stress gage behavior as well as for other studies involving the behavior of soils under dynamic loadings. Interesting results were obtained from all the testing completed; however, it is concluded that further investigations are required to complete the evaluation of the above systems.

During the course of these investigations an earth strain gage and a horizontal displacement meter were developed. However, further testing of these units is required to complete their design.

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PART I

DESIGN OF AN INSTRUMENTED EARTH SHOCK TUBE

Contract DA-36-034-509-ORD-3116RD

1.0 INTRODUCTION

This report, written in two parts, describes the work performed by Atlantic Research Corporation for the Ballistic Research Laboratories under two separate contracts; namely, Contract Nos. DA-36-034-509-ORD-3116RD and DA-18-001-AMC-877(X). The second contract was actually a continuation of the work initiated under the first contract. The time period covered by the two contracts ranged from December 1959 to October 1967.

The effort expended during this time period covered several areas which developed from the investigations into the development of an earth shock tube. For purposes of clarity, the major areas investigated under these contracts are reported herein as follows:

1. Development of an earth strain gage.
2. Design, instrumentation and test of an earth shock tube.
3. Design, instrumentation and evaluation of a dynamic oedometer.[1]
4. Development of a horizontal displacement meter.[2]
5. Design, instrumentation and evaluation of a dynamic triaxial apparatus.[1]

The dynamic triaxial apparatus was never assembled and evaluated because of the limited funding available.

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(1) The design of the dynamic oedometer and the dynamic triaxial apparatus was done under the direction of Dr. Werner Heierli and Alva Matthews of the Paul Weidlinger firm in New York City.

(2) A separate report was published covering the development of the horizontal displacement meter; however, for purposes of continuity, it is reproduced here in its entirety.

2.0 EARTH STRAIN GAGE

2.1 Design

The design of the earth strain gage is shown in Figure 1. The general configuration is two large discs connected axially by a stem of small cross-sectional area. It was hoped that this configuration would reduce soil disturbances caused by the presence of the gage. Encased in the stem is a Bourns Model 141 linear-motion potentiometer, whose resistance element is a carbon film. The manufacturer claims that the associated electronic equipment limits the resolution which can be obtained with this potentiometer. The stem of the transducer is encased within a cylinder which is allowed to slide over the transducer housing, and soil is prevented from entering into the sliding area by a flexible plastic tube cemented to the metal parts at each end. The force needed to overcome the inertia of the system is minimized by the use of aluminum for most metal parts. The nominal transducer slider friction is 4 ounces. The only other restraining force will be contributed by the soil contained between the two discs of the gage. Density-matching of the gage and soil can be accomplished by adding metal to, or taking metal from, the gage housing.

2.2 Circuitry

The gage can be incorporated into several types of electrical circuits. It can be used as a voltage divider, of course, with the slider position indicated as a variable voltage-drop. In addition, it can be considered a variable resistor and used in an a.c. or a d.c. resistance bridge. Hence the earth strain gage can be readily used in several standard measurement and recording systems.

2.3 Evaluation

These gages were utilized in the tests conducted in the earth shock tube. Test results are tabulated and discussed in the following section.

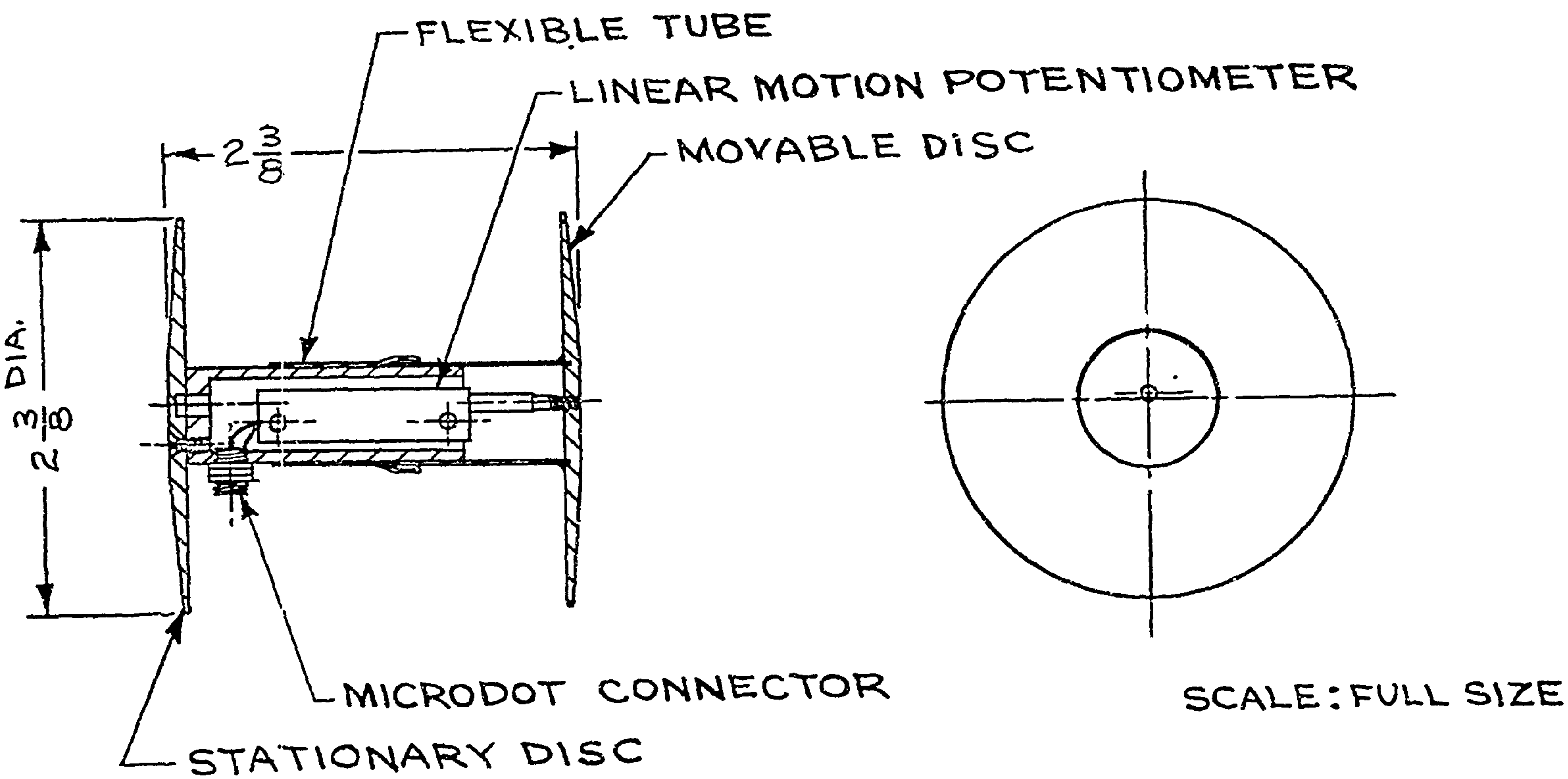

Figure 1. Earth Strain Gage.

3.0 EARTH SHOCK TUBE

3.1 Friction Investigation

In earlier work on the dynamic behavior of soils; e.g., Reference (1), consideration has been given to wave propagation studies using shock tube techniques. Ideally, the lateral strains imposed when the load is applied should not interfere with the axial motion of the particles. However, the frictional effects at the walls of the confining tube were so great that the ideal situation was difficult to achieve. It had been reported that lubrication reduces the wall friction; so it seemed worthwhile to investigate various lubrication techniques. If a large reduction in wall friction could be achieved, the earth shock tube could take a simple form.

3.1.1 Sliding Plate Experiments

In these experiments, a metal plate with various surface treatments was caused to slide over the test surface. The forces required to start the motion and to maintain the motion were measured with a Hunter Force Indicator, Model L-20. Moisture content and compaction of the soil were not controlled, although a new surface of sand was exposed for each sliding test. The measurements, reported as the average of a number of trials along with the maximum observed deviation from the average, are consistent enough to warrant the conclusion that differences in observed frictional forces greater than 10% are probably real.

In the first series of experiments, a metal plate with different surface treatments was caused to slide across a surface of dry sand. The plates are described in Table I, and the measured frictional

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(1) Massachusetts Institute of Technology; the Behavior of Soils under Dynamic Loadings; III Final Report on Laboratory Studies; Contract DA-49-129-ENG-227, Office of the Chief of Engineers, AFSWP-118; August, 1954.

TABLE I

Description of Plates for Table II

Plate 1	Cold rolled steel - frictional surface as received from stock - dimensions 1/2 inch by 6 inches by 6 inches with a 1/2-inch radius on leading edge; weight 5.1 pounds
Plate 2	Cold rolled steel - frictional surface 16 microinch ground finish - dimensions 1/2 inch by 6 inches by 6 inches with a 1/2-inch radius on leading edge; weight 5.0 pounds
Plate 5	Plate 2 with a coat of buffed Dyer's general purpose paste wax.
Plate 6	Plate 1 with a coat of buffed Dyer's general purpose paste wax.
Plate 9	Cold rolled steel - frictional surface Teflon with approximately a cold rolled finish - dimensions 1/2 inch by 6 inches by 6 inches with a 1/2-inch radius on leading edge; weight 5.0 pounds
Plate 10	Plate 2 with a light coat of dry molybdenum disulfide.
Plate 11	Plate 1 with a light coat of dry molybdenum disulfide.
Plate 12	Plate 2 with a light coat of powdered graphite.
Plate 13	Plate 1 with a light coat of powdered graphite.
Plate 14	Plate 2 with a light coat of S-73 plasticizer.

forces are given in Table II. These data indicate the following: Treatment of the metal surface alone can reduce friction by about 50%; the treatments tested were not effective unless the metal surface was polished.

In the second series of experiments, four metal surfaces were tested by sliding over a thin layer of granular material spread over the sand to form a lubricating layer. The metal surfaces are described in Table I and the lubricating layers in Table III. The measurements are reported in Table IV. The data indicate that the friction can be reduced by two-thirds or more by using a lubricating layer of Teflon powder inserted between the soil and the confining wall; a Teflon-coated rough metal surface was almost as effective as a polished metal surface, so far as friction reduction was concerned.

Use of a polished metal surface or a Teflon-coated metal surface to confine the earth in a shock tube might not be practical from the cost point of view. Hence, a series of experiments was carried out with the sliding plate to test the frictional effects of various surface coatings, using cold rolled steel in the "as-received" condition as the base material. The results, given in Table V, show that cellophane sheet and two of the lacquers give as low frictional resistance as the polished metal plate.

3.1.2 Tube Experiments

Friction forces in tubes with an inside diameter of 2.5 inches were next investigated, as an extension of the sliding-plate experiments. Samples of dry and of moist sand were compacted in tubes of various surface finishes, with and without lubricating layers of Teflon powder. The length-to-diameter ratio of the sand column was varied from 5.9 to 1.4 by filling a longer section of the same tube.

TABLE II

Effect of Surface Treatment of Metal Plate
on Frictional Resistance with Dry Sand

Plate No.	No. of Trials	Static: Ave. Static Frictional Resistance (lbs)	Static: Maximum Deviation from Ave. (lbs)	Dynamic: Ave. Dynamic Frictional Resistance (lbs)	Dynamic: Maximum Deviation from Ave. (lbs)
1	10	2.3	0.2	2.3	0.1
2	10	1.6	0.2	1.3	0.2
6	10	1.9	0.3	1.7	0.2
5	10	1.2	0.2	1.0	0.2
9	25	2.2	0.2	2.1	0.3
10	25	1.1	0.2	1.1	0.2
11	25	2.1	0.2	2.1	0.3
12	25	1.1	0.1	1.1	0.2
13	25	2.2	0.3	2.1	0.3
14	30	1.6	0.4	1.5	0.5

(1) See Table I for plate description.

TABLE III

Lubricating Layer Descriptions and Notes

1. Glass bead layer, 1/16" thick, 15 micron to 25 micron size range.

2. Glass bead layer, 1/16" thick, 350 micron to 500 micron size range.

3. Sand-graphite mixture, 1/8" thick layer, 5% graphite by volume.

4. Glass bead-molybdenum disulfide mixture, 1/16" thick layer, glass bead size range 350 micron to 500 micron, 1% molybdenum disulfide by volume.

5. Teflon powder layer, 1/8" thick, grain size unknown.

6. Teflon powder layer, same as Number 5. Layer was placed on moist sand in a shallow pan and then sealed with aluminum foil. The assembly remained intact for 3 days before the tests were conducted. Initial and final weight checks of the pan revealed no loss of weight after the 3-day period, within the accuracy of the measurement method. However, the surface of the lubricating layer may have dried out during the friction measurements.

TABLE IV

Effect of Lubricating Layers on Frictional Resistance

Plate (1) No.	Layer (2) No.	No. of Trials	Sand Condition	Static: Ave. Static Frictional Resistance (lbs)	Static: Maximum Deviation from Ave. (lbs)	Dynamic: Ave. Dynamic Frictional Resistance (lbs)	Dynamic: Maximum Deviation from Ave. (lbs)
1	1	10	Dry	2.1	0.1	2.0	0.1
2	1	10	Dry	1.9	0.1	1.8	0.1
9	1	10	Dry	2.0	0.2	2.0	0.1
10	1	10	Dry	1.7	0.1	1.7	0.1
1	2	10	Dry	1.5	0.1	1.3	0.1
2	2	10	Dry	1.2	0.1	1.1	0.1
9	2	10	Dry	1.4	0.1	1.4	0.1
10	2	10	Dry	1.1	0.1	1.1	0.1
1	3	10	Dry	2.5	0.1	2.4	0.2
2	3	15	Dry	1.7	0.2	1.7	0.2
9	3	10	Dry	2.0	0.1	2.0	0.1
1	4	10	Dry	1.5	0.1	1.5	0.1
2	4	10	Dry	0.9	0.2	0.9	0.2
9	4	10	Dry	1.1	0.1	1.1	0.1
10	4	10	Dry	0.9	0.2	0.9	0.2
1	5	10	Dry	1.0	0.2	0.9	0.1
2	5	10	Dry	0.6	0.1	0.6	0.1
9	5	10	Dry	0.7	0.3	0.6	0.1
9	6	10	Moist	1.0	0.1	0.9	0.1
1	6	10	Moist	0.9	0.2	0.8	---
2	6	10	Moist	0.6	0.1	0.6	---
9	6	10	Moist	0.7	0.3	0.7	0.1

(1) See Table I for plate description.

(2) See Table III for layer description.

TABLE V

Effect of Surface Treatment of Metal Plate on Frictional Resistance with Dry Sand and Teflon Powder Layer

Plate: Cold rolled steel with "as received" surface
Dimensions: 1/2 inch by 6 inches by 6 inches with 1/2 inch radius on leading edge; weight 5.0 lbs

Sand Condition: Dry

Lubricating Layer: Teflon Powder No. 1 (600 micron grain size)

Frictional Surface	No. of Trials	Static: Ave. Static Frictional Resistance (lbs)	Static: Maximum Deviat. fr. Ave. (lbs)	Dynamic: Ave. Dynamic Frictional Resistance (lbs)	Dynamic: Maximum Deviat. fr. Ave. (lbs)	Remarks
Acetate sheet	10	0.8	0.1	0.8	0.2	0.007" thick, surface glossy
Cellophane sheet	10	0.6	0.1	0.6	0.1	0.002" thick, surface glossy
Mylar sheet	10	1.3	0.1	1.2	0.1	0.001" thick, surface glossy with wrinkles
Mylar sheet	10	0.8	0.2	0.8	0.1	0.005" thick, surface glossy
Polyethylene sheet	10	0.9	0.1	0.9	---	0.005" thick, surface semi-glossy
Plexiglas sheet	10	0.8	0.1	0.8	0.1	0.020" thick, surface glossy
Polystyrene sheet	10	1.4	0.2	1.1	0.2	0.022: thick, surface satin
Aluminum foil	10	0.8	0.1	0.8	0.1	0.002" thick, surface bright with wrinkles
Araldite	10	1.5	0.3	1.5	0.3	Cured 1 hour at 150° F and 1 hour at 75° F.
Araldite	10	1.9	0.2	2.0	0.3	Preceding plate tested after 5 days.
"Krylon" Clear Acrylic Resin No. 1302	10	2.7	1.3	0.9	0.4	Three coats cured as per directions.

TABLE V (continued)

Frictional Surface	No. of Trials	Static: Ave.Static Frictional Resistance (lbs)	Static: Maximum Deviat. fr. Ave. (lbs)	Dynamic: Ave.Dynamic Frictional Resistance (lbs)	Dynamic: Maximum Deviat. fr. Ave. (lbs)	Remarks
"Krylon" Enamel No. 1605	10	0.9	---	0.7	0.3	Four coats cured for 16-1/2 hours at room temperature
Lacquer, Glidden No. 2838	10	0.5	0.1	0.5	0.1	Two coats cured for 3 hours at room temperature.
Lacquer, Glidden No. 2838	10	0.7	0.1	0.8	0.1	Four coats cured for 2 hours at room temperature. Surface dust laden.
Lacquer, Glidden No. 2838	10	0.7	0.1	0.7	0.1	Two coats cured for 18 hours at room temperature. Surface dust laden.
Lacquer, Spray, Illinois Bronze Powder Co., No. 130	10	0.6	0.2	0.6	---	Two coats cured for 2 days at room temperature.
Glyptol No. 1202	10	1.2	0.1	1.2	0.1	Cured for 3 days at room temperature Surface dust laden.

Note:

The average static frictional resistance for a cold rolled steel plate with a 16-microinch finish sliding on a lubricating layer of Teflon powder, measured under comparable conditions, is 0.6 lbs; see Table IV.

To install the Teflon layer, a thin-walled aluminim tube with an outside diameter of approximately 2 1/8 inches was inserted along the axis of the larger tube and was held in place by a plug inserted in the bottom of the larger tube. The annular gap was filled with Teflon powder and the inside tube with sand. The smaller tube was then withdrawn and the contents of the larger tube compacted.

The first experiments with tubes were qualitative, to learn whether the general aspects of the sliding-plate experiments would be confirmed in tubes. After the compaction process, the tube was lifted vertically upwards, the bottom plug was removed, and the tendency of the sand column to fall out of the tube was observed. The results, given in Table VI, are consistent with the results of the sliding plate experiments and indicate that the Teflon powder layer confined by a polished metal surface does provide lubrication. There is some indication of an effect of particle size, although the corrosion of the polished steel surface may have influenced the results. Visual inspection of the cross sections of the sand columns showed a uniform layer of Teflon powder, indicating that the installation technique was satisfactory.

In the second series of experiments with tubes, an attempt was made to obtain semi-quantitative data concerning the frictional resistance. The tube was held rigidly in place, vertically, and the Hunter Force Indicator was attached to the bottom retaining plug. The bottom plug was then lowered until its top surface was level with the bottom of the tube, in order to eliminate friction between the plug and the tube. The force of the sand column on the plug was observed. The results are given in Table VII. About 70% of the weight

TABLE VI

Results of Experiments on Frictional Effects in Tubes

Tube Finish	L/D(2)	Sand Condition	Lubricating Layer	Results
Cold rolled	5.8	Dry and highly compacted	None	Column fell freely out of tube.
Cold rolled	4.5	Water-saturated and highly compacted	None	Column remained intact in tube.
Cold rolled	2.3	Moist and highly compacted	None	Column remained intact in tube.
Cold rolled	1.5	Moist and highly compacted	None	Column remained intact in tube.
Cold rolled	1.4	Moist and highly compacted	Teflon powder(1)	Column remained intact in tube
16-microinch	1.5	Moist and highly compacted	Teflon powder(1)	Column slowly slid out of tube.
16-microinch	5.4	Moist and highly compacted	Teflon powder(1)	Column fell freely out of tube.
16-microinch	1.2	Moist and highly compacted	None	Column remained intact in tube.
16-microinch, pitted	5.4	Moist and highly compacted	Teflon 5	Broke in half; one half fell out of tube and other half remained intact in tube.
16-microinch, pitted	5.3	Saturated and highly compacted	Teflon 5(1)	Column slowly slid intact out of tube.
16-microinch, pitted	5.0	Moist and highly compacted	Teflon 7(1)	Column remained intact in tube.

(1) Grain sizes:
Teflon powder: size unknown
Teflon 5: 350 micron
Teflon 7: 35 micron

(2) L/D: length-diameter ratio

TABLE VII

Effect of Lubricating Layer on Behavior of Sand Column in Vertical Tubes

Tube[1] No.	L/D[2]	Teflon[3] Powder	Condition[4] of Sand	Column Weight (lbs)	Measured Force on Bottom of Column (lbs)	Column Weight on Bottom (%)	Remarks
1	5.6	5	MC	4.0	2.2	55	------
1	5.6	5	MC	4.0	2.0	50	Column above was recompacted and test was rerun.
2	4.8	5	MC	3.4	2.4	71	------
2	5.6	5	MC	3.6	2.4	67	------
2	5.6	5	MC	3.6	3.1	86	Side of tube was lightly tapped with hammer.
2	5.4	1	MC	4.2	1.7	40	------
2	4.6	1	MC	3.7	1.3	35	------
2	3.9	1	MC	2.4	1.1	46	------
2	2.9	1	MC	1.8	0.9	50	------
2	5.2	5	DC	2.9	2.5	86	Compaction of column proved to be difficult.
2	5.9	--	DC	4.3	0.4	9.3	Compaction of column proved to be difficult.
3	5.5	5	MC	3.4	1.0	29	------
3	5.5	5	MC	3.4	1.9	56	Side of tube was lightly tapped with hammer.
3	5.5	5	MC	3.4	2.5	74	Measurement was made after 1-1/2 hours.
4	5.5	5	MC	4.0	---	--	Column did not slide out of tube.
4	5.5	5	MC	4.0	1.3	32	Column was pushed slightly to start.

TABLE VII (continued)

Tube (1) No.	L/D (2)	Teflon (3) Powder	Condition (4) of Sand	Column Weight (lbs)	Measured Force on Bottom of Column (lbs)	Column Weight on Bottom (%)	Remarks
4	5.5	5	MC	4.0	1.4	35	Measurement made after 1/2 hour.
4	5.5	5	MC	4.0	1.4	35	------
5	5.5	5	SC	3.6	0.6	17	Teflon powder wet
5	5.8	5	MC	3.4	1.5	44	------
5	5.8	5	MC	3.4	1.4	41	------
5	5.8	5	MC	3.4	1.7	50	------
5	5.8	5	MC	3.4	1.8	53	------
5	5.8	5	MC	3.4	1.4	41	------
5	5.8	5	MC	3.4	1.6	47	------

Notes:

(1)

Tube No.	Description
1	Cold rolled steel, inside surface Teflon coated, tube originally honed to 16-microinch surface
2	Cold rolled steel, inside surface honed to a 16-microinch finish
3	Cold rolled steel, inside surface honed to a 16-microinch surface and then bright chrome plated, thickness 0.00001 inch.
4	Cold rolled steel, inside surface honed to a 16-microinch surface and then copper and nickel plated as per Federal Specification QQ-N-290, Class I, Type II, and then chrome plated as per Federal Specification QQ-C-320 Class I, Type I. Frictional surface had a smooth bright chrome finish.
5	Stainless steel, Type 304; inside surface honed to a 13-microinch surface.

(2) L/D: Length-diameter ratio of column

(3) Teflon powder grain sizes
Teflon 1: 600 microns
Teflon 5: 350 microns

(4) MC: Moist and compacted
DC: Dry and compacted
SC: Saturated and compacted

of a column of moist and compacted sand was supported by the bottom plug, when a layer of Teflon powder No. 5 was inserted between the sand and the polished cold rolled steel confining wall. Without the lubricating Teflon layer, there would have been no force on the bottom plug.

Finally, three tests were conducted to measure the pushing force required to move a column of moist compacted sand, with and without the Teflon powder layer, in a horizontal tube. The tube assemblies were prepared in the manner described above. The bottom plug was removed, and the cavity end of the tube was placed against a rigid retaining wall. The plug, with Hunter Force Indicator attached, was then used to start motion from the other end of the tube. The observations are presented in Table VIII. For these particular experimental conditions, which may not be optimum for low friction, the Teflon powder lubricating layer reduced the friction to less than 10% of the value measured without the lubricating layer.

3.1.3 Dynamic Tests

A few tests under dynamic conditions were carried out with an accelerometer buried in the sand column in the 2 1/2-inch-diameter tube. A falling weight applied a force pulse to the sand column, and the output of the accelerometer was displayed on an oscilloscope. The wave form was fairly well reproduced in successive trials. However, the amplitudes varied somewhat, attributed to variations in the compaction of the sand and in the nature of the applied pulse. It seemed unlikely that this technique could be used successfully in evaluating the effectiveness of the lubricating layer, so the tests were discontinued. It would probably be better to use a tube large enough so that several accelerometers, placed at different locations with respect to the wall, could be used simultaneously.

TABLE VIII

Frictional Resistance Effects in Horizontal Tubes

Tube[1] No.	L/D[2]	Teflon[3] Powder	Condition[4] of Sand	Column Weight (lbs)	Static Pushing Force (lbs)
4	5.9	NONE	MC	4.5	Exceeded 20[5]
5	6.9	NONE	MC	4.7	Exceeded 20[5]
5	5.8	5	MC	3.4	1.8

Notes:

(1) See Table VII for tube description.

(2) L/D: Length-diameter ratio of column.

(3) Teflon 5: 350 micron grain size.

(4) MC: moist and compacted.

(5) Limit of gage is 20 pounds.

3.2 Force Application Hyge Shock Tester

The earth shock tube must include a method for applying a force to the soil surface. The force should rise to its maximum value in a few milliseconds and maintain that value approximately constant for a minimum of 30 milliseconds and preferably for a much longer time. The pressure s ould be about 500 psi. The Hyge Shock Tester seemed to meet these requirements.

3.2.1 Principle of Operation

A diagram of the Hyge Shock Tester is shown in Figure 2. The Tester is basically a cylinder divided into two chambers by an orifice plate. Chamber A is sealed from Chamber B by two sealing rings, one at the periphery of the thrust piston and the other at the relatively small orifice leading into Chamber B. When Chamber A is pressurized to a low value the thrust piston seats itself against the orifice opening, thus exposing a small piston area to Chamber B. High values of pressure, therefore, are needed in Chamber B to balance the forces on the piston produced by the low gas pressure in Chamber A. A slight increase in pressure over the equilibrium pressure moves the thrust piston in Chamber A, and the seal at the orifice is destroyed. The high pressure in Chamber B then acts on the entire surface of the thrust piston and rapidly moves the piston further into Chamber A. The acceleration and deceleration of the thrust piston is precisely controlled by metering the flow of gases. The thrust pulse is transferred to the thrust column which can be attached to any desired object.

The Model HY6407 Hyge Shock Tester, available at Atlantic Research Corporation, can produce a thrust of 40,000 pounds with a thrust column travel of a fraction of an inch. This force applied to a column of soil ten inches in diameter would give a

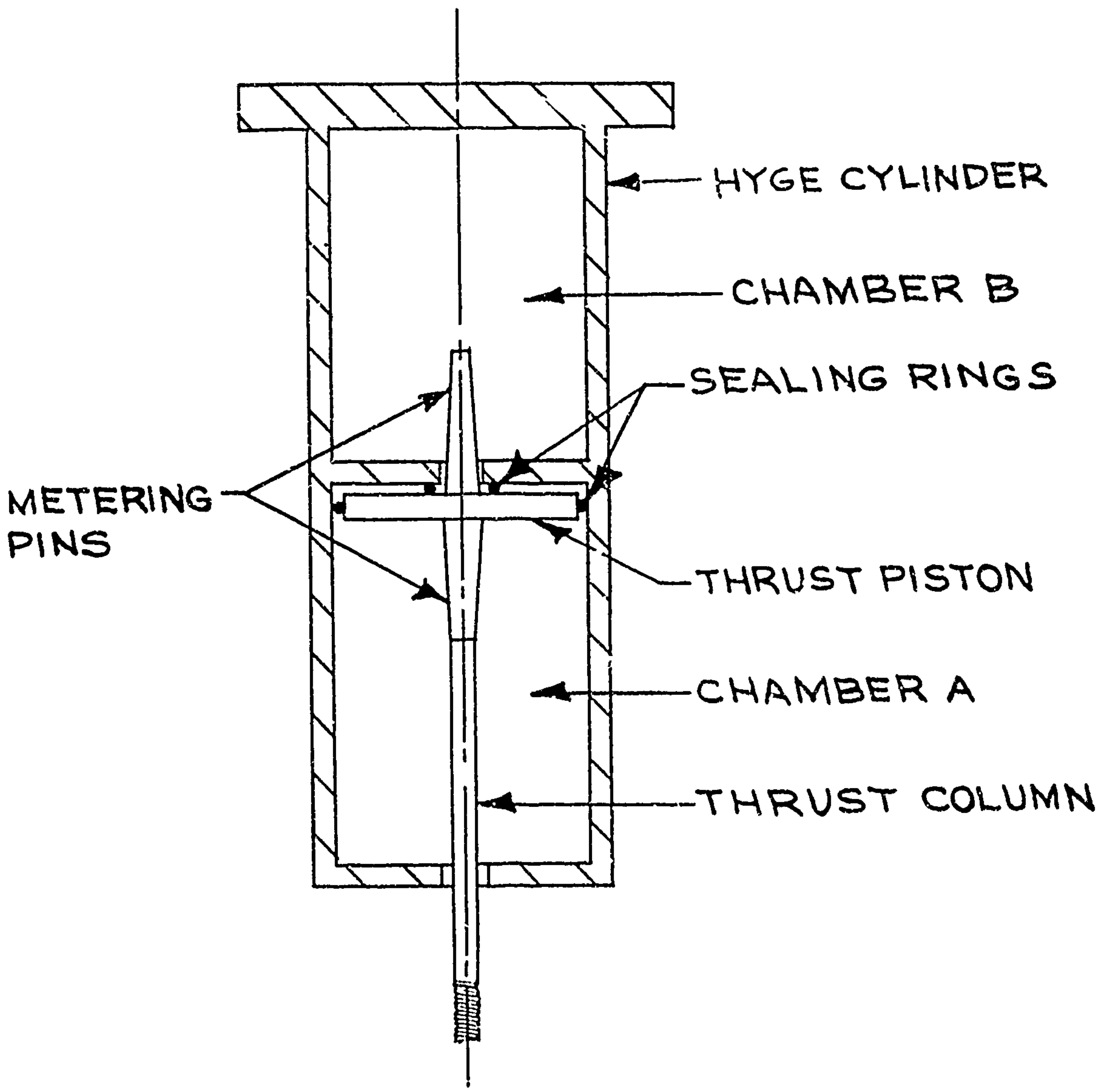


Figure 2. Hyge Shock Cylinder.

pressure somewhat greater than 500 psi. The rise times of thrust pulses produced by this model have been reported to be between 5 milliseconds and 10 milliseconds; however, shorter rise times were possible if a specially designed metering pin was used. These performance characteristics appeared suitable for the purpose described here.

3.3 Modification and Mounting of the Hyge Shock Tester

3.3.1 Hyge Cylinder

The cylinder end of the Hyge unit was securely fastened to a rigid cross-member composed of two 12-inch I-beams (Figure 3). Under a dynamic load of 40,000 pounds, the theoretical deflection of this composite beam, at the Hyge unit, was 0.03 inch. A Baldwin-Lima-Hamilton, Type C, wire strain gage load cell was attached to the thrust column to record the wave form of the input pulse. The cell was capable of measuring 50,000 pounds of thrust within an accuracy, as stated by the manufacturer, of $\pm$ .25% of full-scale output at 70° Fahrenheit. The loading button of the load cell bears on a replaceable heat treated plate which is attached to the semi-floating piston assembly.

3.3.2 Structural Steel Components

All structural steel material used in the structure conformed to the American Society for Testing Materials "Standard Specifications for Structural Steel for Bridges and Buildings, Serial Designation A-7." The slenderness ratios of all columns for both compression and tension were well within the values specified by the American Institute Of Steel Construction. Plumbing of the main columns and the earth shock tube support was facilitated by use of metal plates imbedded in the concrete. Lateral motions of the cross-member were minimized by rods attached to the 12-inch I-beams on the inside of the main columns. Removal of the cross-member

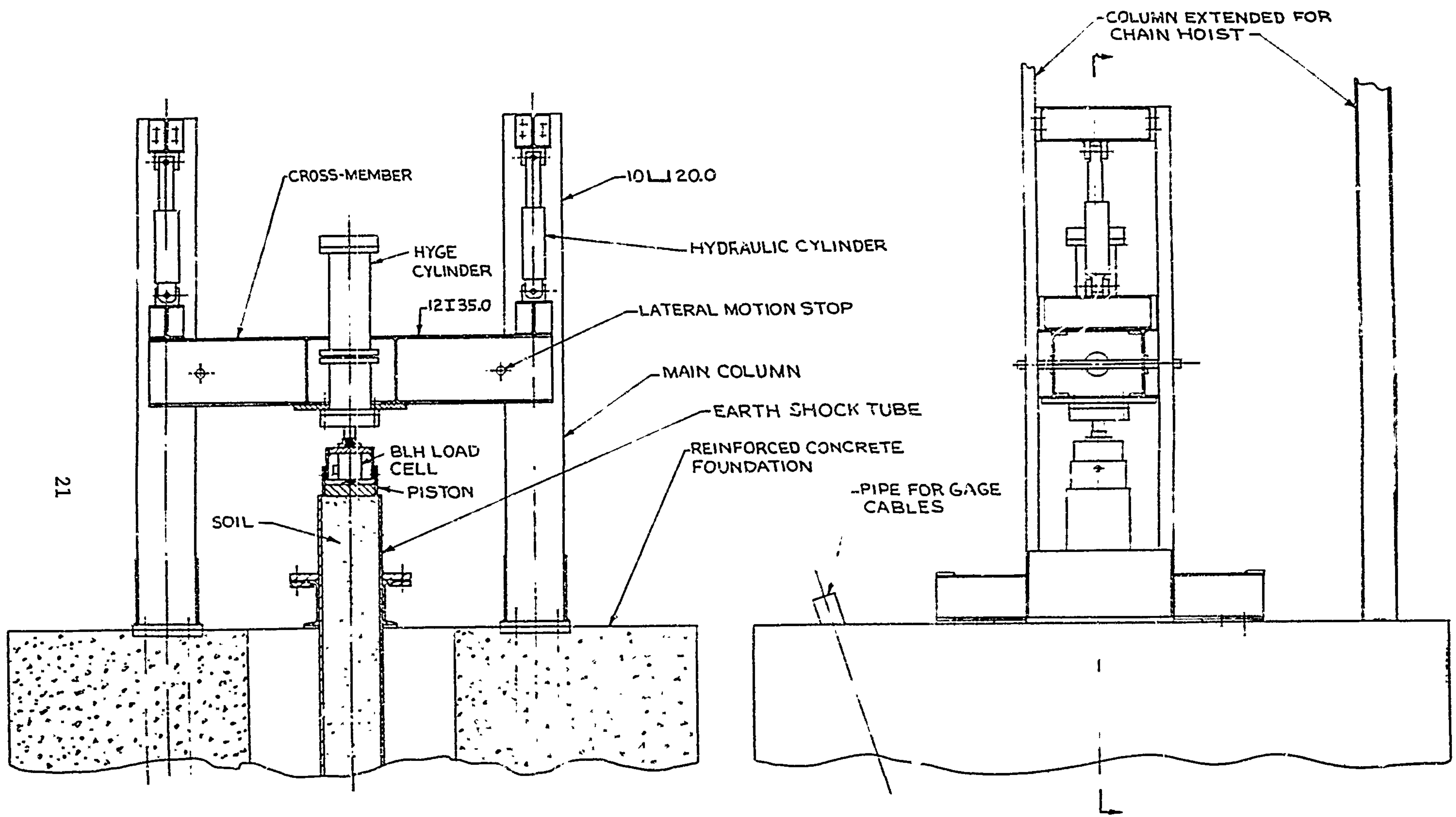


Figure 3. Hyge System for Soil Measurement Program.

from the structure was accomplished by removing the lateral motion stops and disconnecting the lower hydraulic cylinder pins. The Hyge cylinder could then by removed from the cross-member. A structural arrangement (not completely shown in the sketch) supported a chain hoist which was used to handle the heavier components of the system.

3.3.3 Hydraulic Jacks

Two Dynex, Inc., high-pressure, double-acting cylinders (Figure 4) were used both to transmit the Hyge load to the main columns and to adjust vertically, within 9 inches, the Hyge cylinder to accommodate different soil sample heights in the shock tube. These cylinders could be used to preload the soil in the shock tube to simulate conditions at various depths in the earth. Each cylinder was capable of withstanding 22 tons of force in the push direction and 6 tons of force in the opposite direction at a cylinder pressure of 6000 psi. The manufacturer stated that the cylinder would not collapse under load when fully extended.

To move the cylinders, a Dynex double-acting hydraulic hand pump was used. With a fluid displacement of 0.294 cubic inch per stroke, 22 strokes of the pump were required to move the cylinder 9 inches. Handle effort was determined by the acting pressure, with a maximum of 79.2 pounds at a pressure of 6000 psi.

3.3.4 Concrete Foundation

The foundation for the shock tube and Hyge Tester was built in accordance with suggestions made by the Consolidated Electrodynamics Corporation who supplied the Hyge Tester. It contained more than 800 cubic feet of reinforced concrete and was in the snape of a cube 10 feet on each edge with a hole in the center 3 feet in diameter to accept the

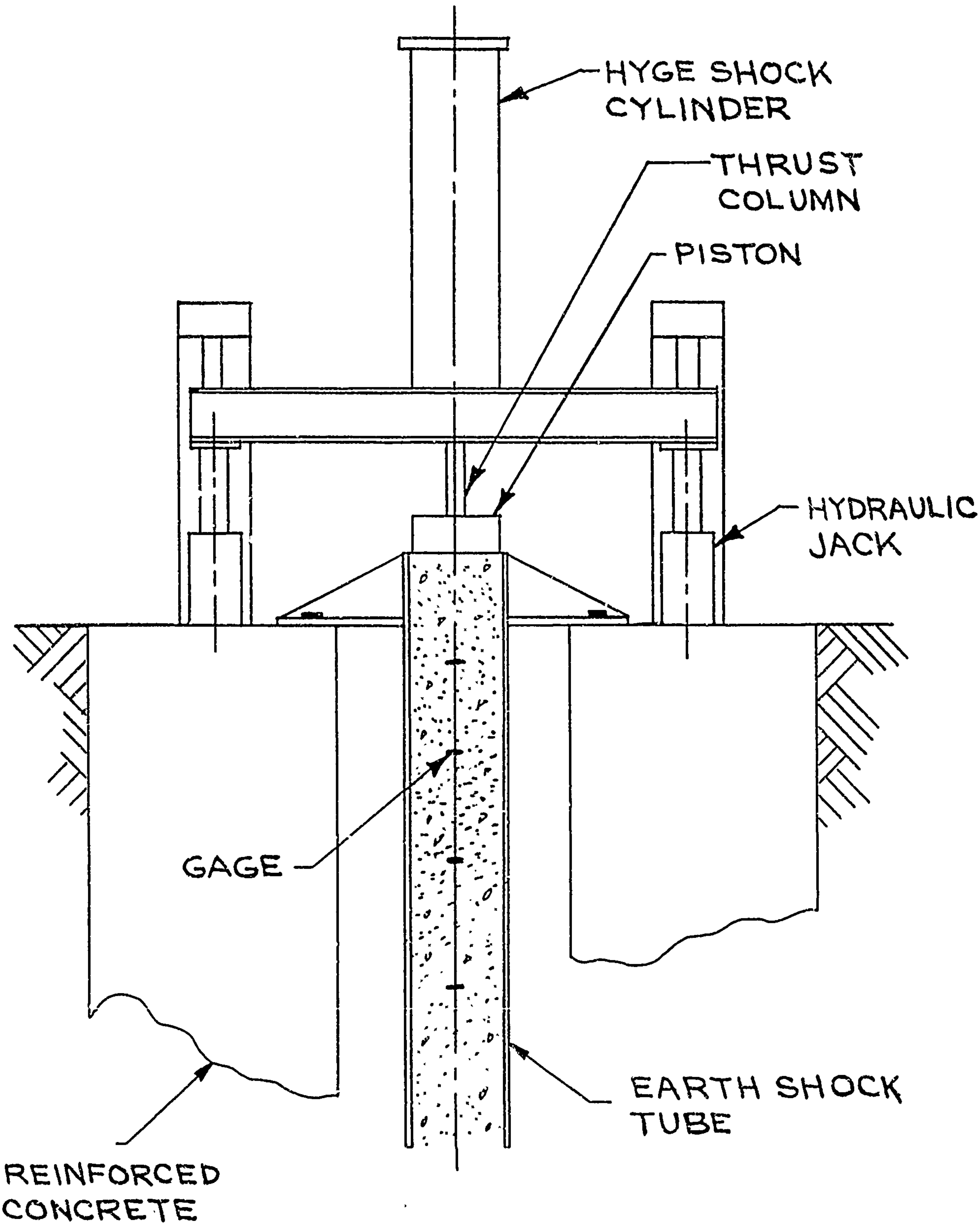


Figure 4. Hyge Shock System.

shock tube. Seven feet of the block was below the earth's surface. To accommodate gage cables from the instruments in the shock tube, a 4-inch pipe or conduit was imbedded in the concrete with one end extending above the top surface of the concrete block and the other end intersecting the 3-foot diameter hole at the lower surface.

3.3.5 Shock Tube

The 10-foot long shock tube, which has an inside diameter of 10 inches, was securely fastened to the concrete foundation by means of two 8-inch structural channels straddling the 3-foot diameter hole. Plumbing of the tube was facilitated by bolting the assembly to steel plates imbedded in the concrete. It was planned to follow the procedure previously used in the laboratory experiments to assemble the tube, sand, Teflon powder (when used) and instruments.

3.4 Test Series No. 1

With the assistance of BRL technical personnel, a preliminary test was carried out to check the performance of the earth shock tube system which had been constructed. The system performed generally as expected, and it appeared that only minor modifications and adjustments were required.

3.4.1 Experimental Arrangement

The input force pulse generated by the Hyge cylinder was measured by a Baldwin-Lima-Hamilton Type C load cell. Soil stress was measured by modified BRL (oil-coupled) stress gages, and acceleration by Wiancko Type A 1023 accelerometers. Atlantic Research Corporation earth strain gages were installed, but gave no records because their range was exceeded during the first one or two trials before the recorders were operating.

The shock tube, with no liner, was filled with moist, clean building sand, the gages being

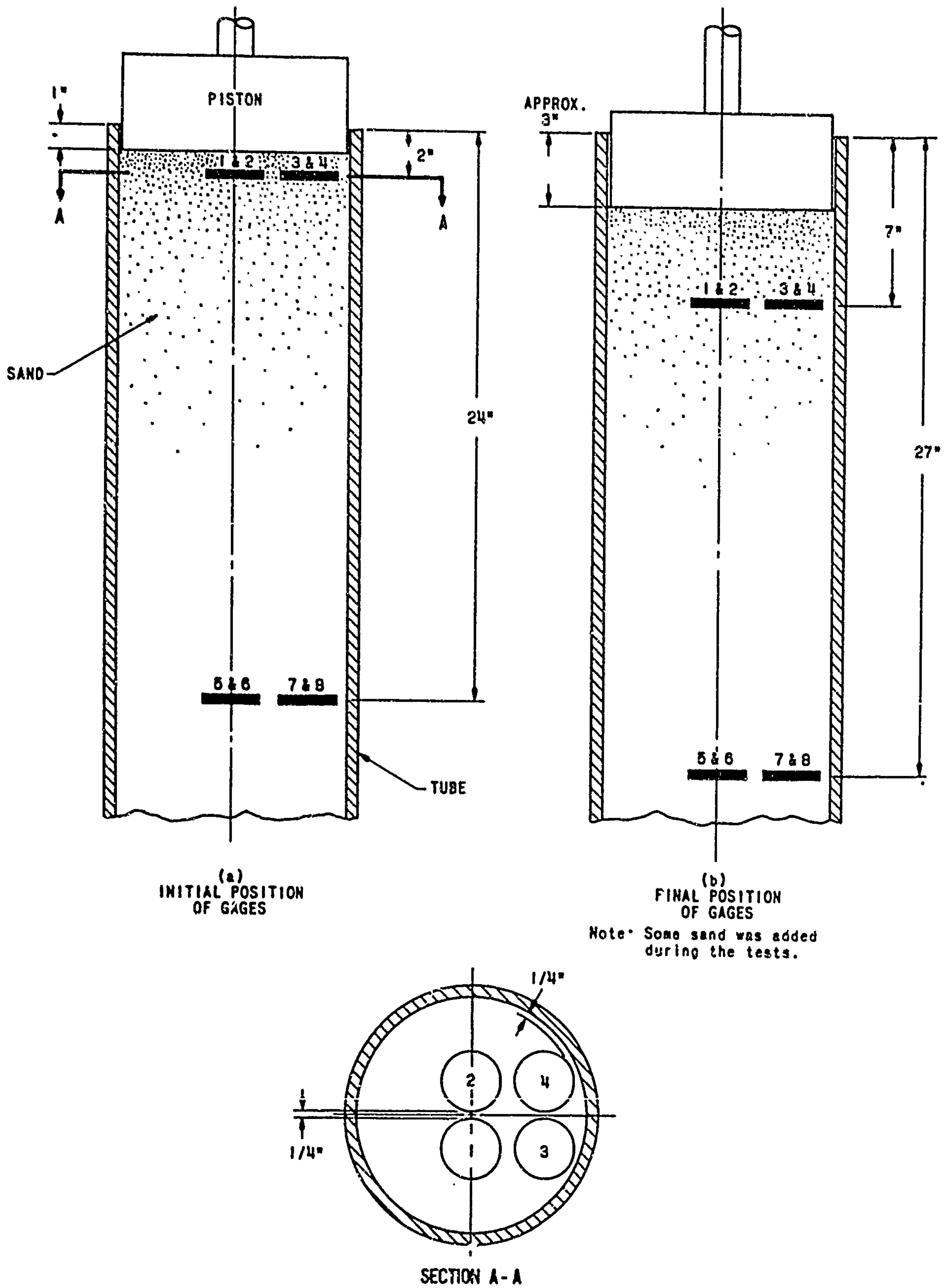
installed and carefully hand-tamped at the chosen levels during the filling. Two gages of each type, one at the center and one at the edge of the tube, were installed at different levels. No particular difficulty was experienced in locating and connecting the gages. The initial and final locations of the stress gages and of the accelerometers are shown in Figure 5. The strain gages were installed at different levels and are not shown in the figure.

3.4.2 Experimental Procedure

The Hyge cylinder was aligned with the earth shock tube by individual operation of the hydraulic jacks. Leveling of the semi-floating piston was accomplished by tapping on the appropriate side. After alignment was completed, the Hyge cylinder was lowered until the load cell button made contact with the bearing plate attached to the piston and resting on the soil surface. The amount of preload on the piston was measured by observing the deflection of the recorder galvanometer connected to the load cell. The Hyge cylinder was then charged and fired and the gage outputs recorded by the CEC recorder.

The sand column was compacted several inches by the first two or three applications of force, to a level beyond the range of adjustment of the hydraulic jacks; therefore, additional sand was placed in the tube to bring the surface to approximately one inch from the top of the tube. Sand was not added after the first two or three shots, but the piston was lowered to the displaced soil surface for the next force application.

The gages were not disturbed during the tests. Afterwards, the sand was carefully removed and the locations of the gages with reference to the top of the tube were measured.



GAGES:
STRESS 1,3,5,7
ACCELEROMETERS 2,4,6,8

Figure 5. Position of Gages - Test Series Number 1.

3.4.3 Observations

3.4.3.1 Equipment Performance

This preliminary investigation indicated that this system for the rapid application of force to a column of earth performed satisfactorily. Minor problems that required solution were the following: adjustment and measurement of the preload on the piston; centering the piston in the shock tube; and removal of air trapped in the hydraulic cylinders. At high forces, a relatively small damped oscillation was evident in the applied force.

The firing pressure of the Hyge cylinder depended on the preload on the piston. If this load was too great, the piston would not fire; if it was zero, the load cell button impacted on the bearing plate. Control and measurement of the preload needed improvement. In later work, the load cell was kept in contact with the piston at all times by a spring device.

The piston was about 3/32 inch off center. Examination of the piston and the tube after the tests showed that there was no binding between the components during the tests. However, the condition was corrected before further tests.

As the Hyge cylinder fired, it was noted that the cross-member attached to the cylinder moved upwards. The maximum movement, on Shot No. 3, was about 1/2 inch. This action was attributed to air trapped in the hydraulic cylinders, a condition which was corrected before further tests were performed.

3.4.3.2 Gage Records

Several good records were obtained in these preliminary tests. As an illustration of the kind of data which can be expected, Figure 6 shows the records obtained from the load cell and from the two stress gages at the upper level in Shot No. 3 and Shot No. 5. The maximum stresses recorded in these two tests are tabulated below.

Observed Peak Stress

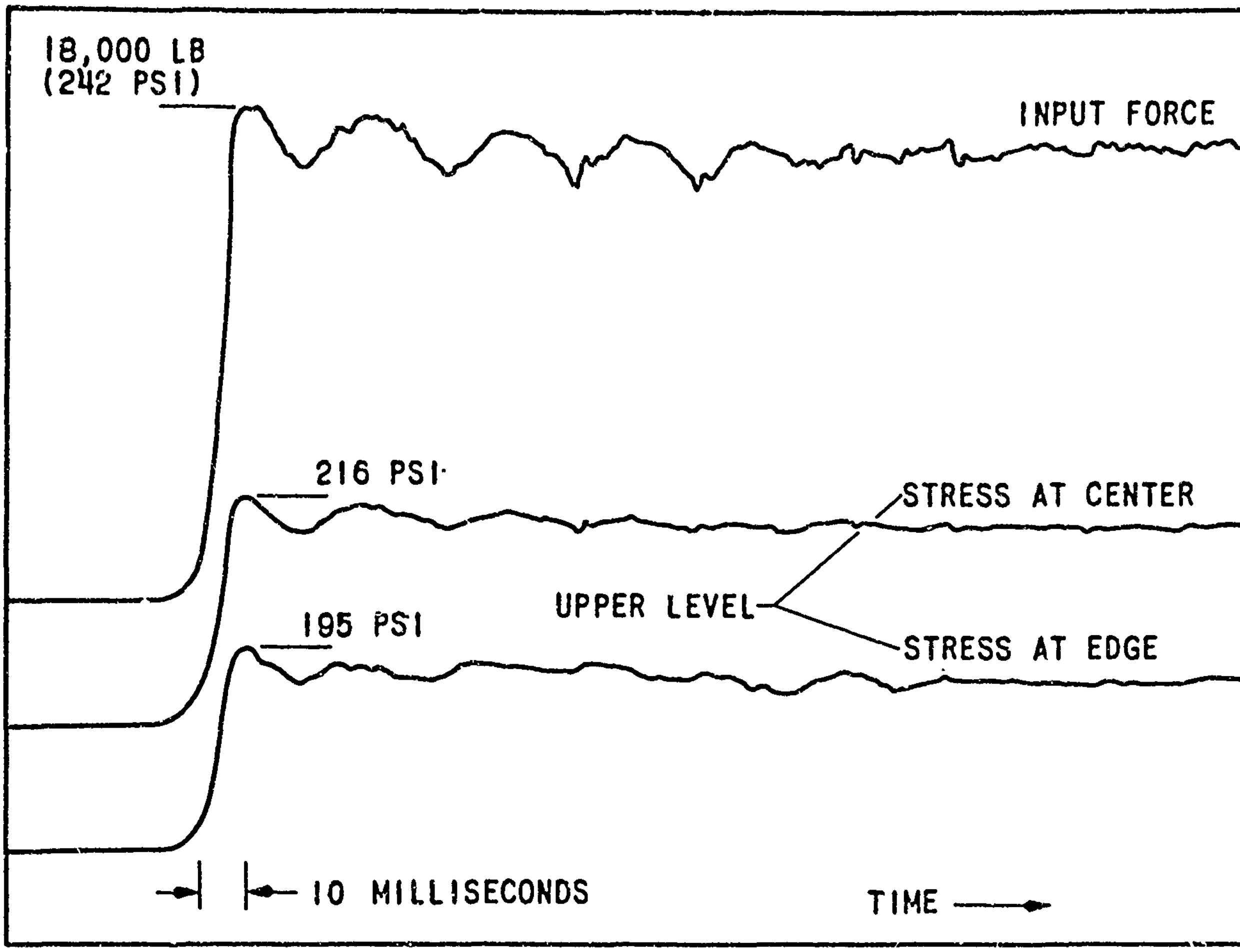
	Shot No. 3 Applied Stress: 242 psi		Shot No. 5 Applied Stress: 74 psi	
	Center (psi)	Edge (psi)	Center (psi)	Edge (psi)
Upper Level	216	195	71	59
Lower Level	24	25	1.9	1.6

Records were obtained from the accelerometers but not from the strain gages.

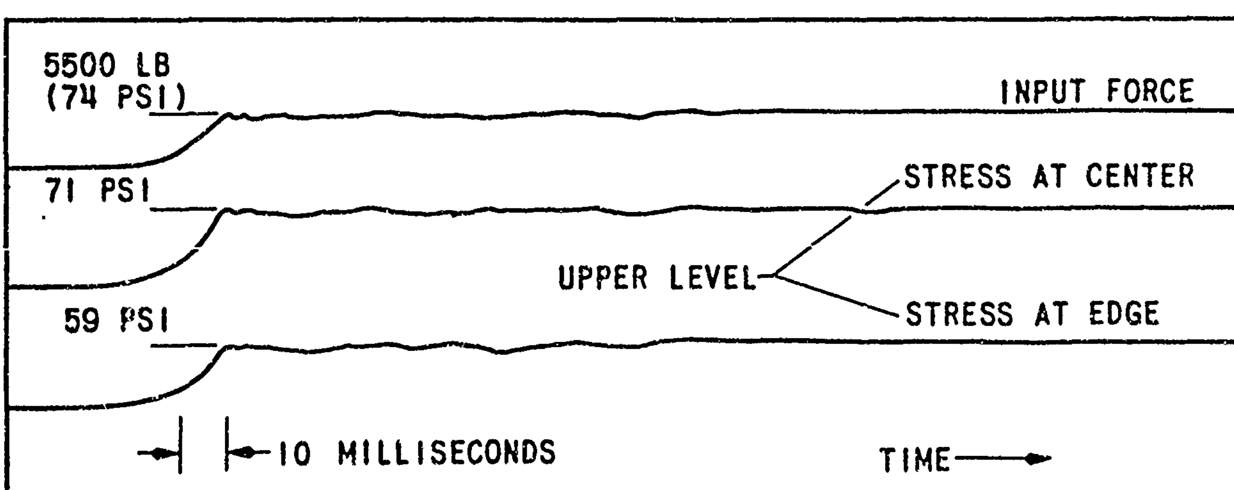
3.4.3.3 Instrument Performance

The stress gages and the accelerometers seemed to have performed satisfactorily. Visual observation of the deflections of the galvanometers during the first one or two force applications indicated that the strain gages were operating initially but failed when their range was exceeded. It was later determined that the stop for the linear motion potentiometer, the transducing element of the strain gage, was damaged. As a result of this test, the design of the strain gage was modified.

The gages were excavated carefully after the tests. They appeared to have moved parallel to the axis of the tube, without turning. Within the error of observation, gages near the edge of the tube



SHOT NUMBER 3



SHOT NUMBER 5

Figure 6. Stress Data Obtained from Earth Shock Tube.

moved the same distance as gages at the same initial level near the center.

3.5 Test Series No. 2: Simple Sand-Filled Tube

The purpose of Test Series No. 2 was to obtain data with a simple sand-filled tube to assist in the investigation of the proposed friction-reduction system using Teflon powder.

3.5.1 Experimental Arrangement

Centering the piston was not accomplished because the easily available adjustments were not sufficient; however, careful observation indicated that the piston was not enough off center to come in contact with the side of the tube during operation. Photographs of the installation are given in Figure 7.

Because of their smaller size, CEC Type 4-202 accelerometers were substituted for the Wiancko accelerometers used previously. Otherwise the instrumentation was the same: Baldwin-Lima-Hamilton load cell, modified BRL (oil-coupled) stress gages, and Atlantic Research Corporation strain gages. The gages were located at two levels. In the first two groups of tests, stress and acceleration gages were located at different levels to avoid crowding the gages. In the third group of tests, the stress and acceleration gages were located at the same levels. The original and final locations of the gages are shown in Figures 8 and 9.

3.5.2 Experimental Procedure

Test Series No. 2 was carried out in three groups. Before each group, sand was excavated to a depth of about 27 inches and the tube was filled with fresh sand, tamped by hand. During excavation, the distance of each gage from the top of the tube was measured. During the filling operation, the gages were installed at the selected levels.

Figure 7. Photographs of Hyge System for Soil Measurement Program.

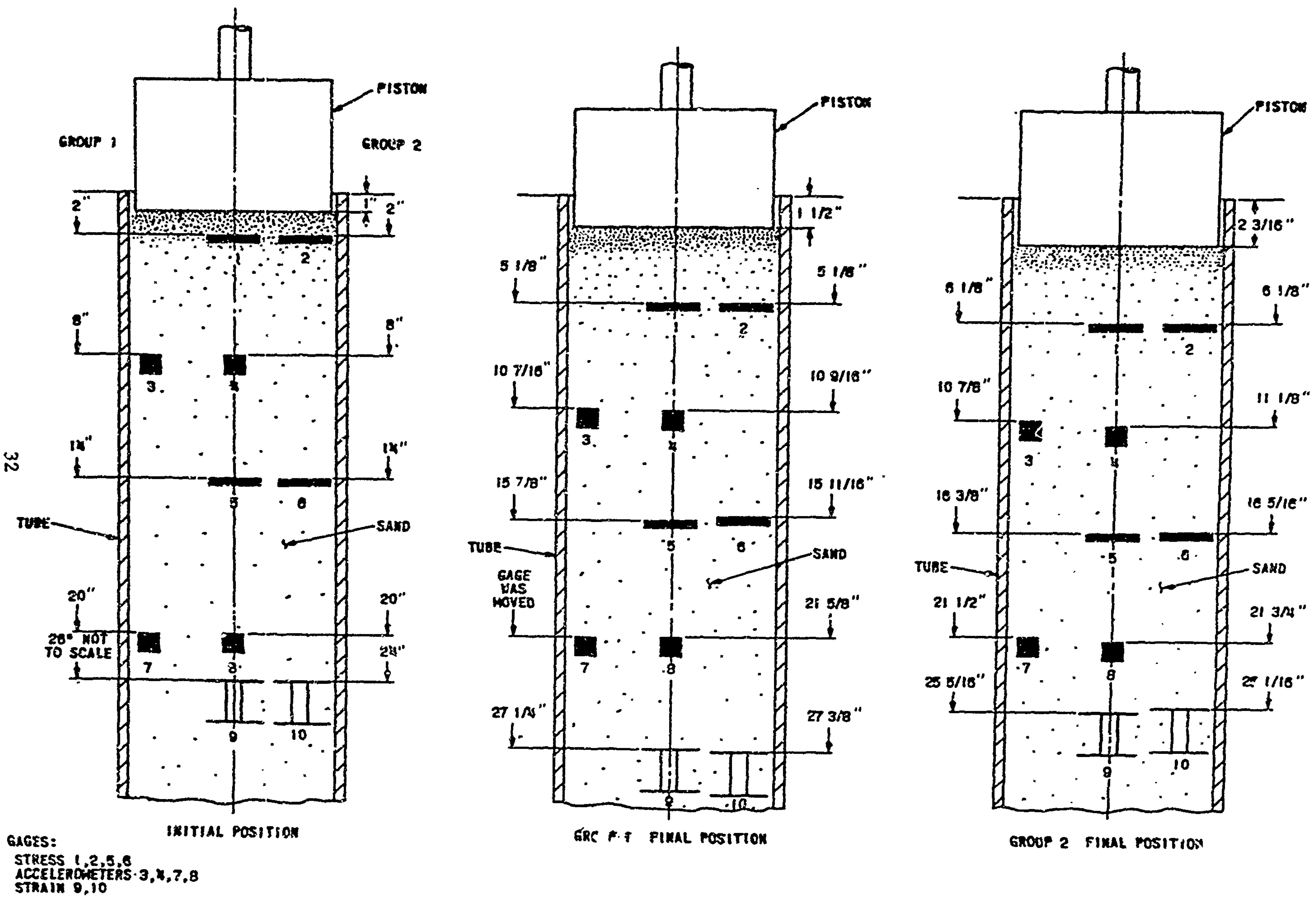


Figure 8. Position of Gages in Test Series Number 2, Groups 1 and 2.

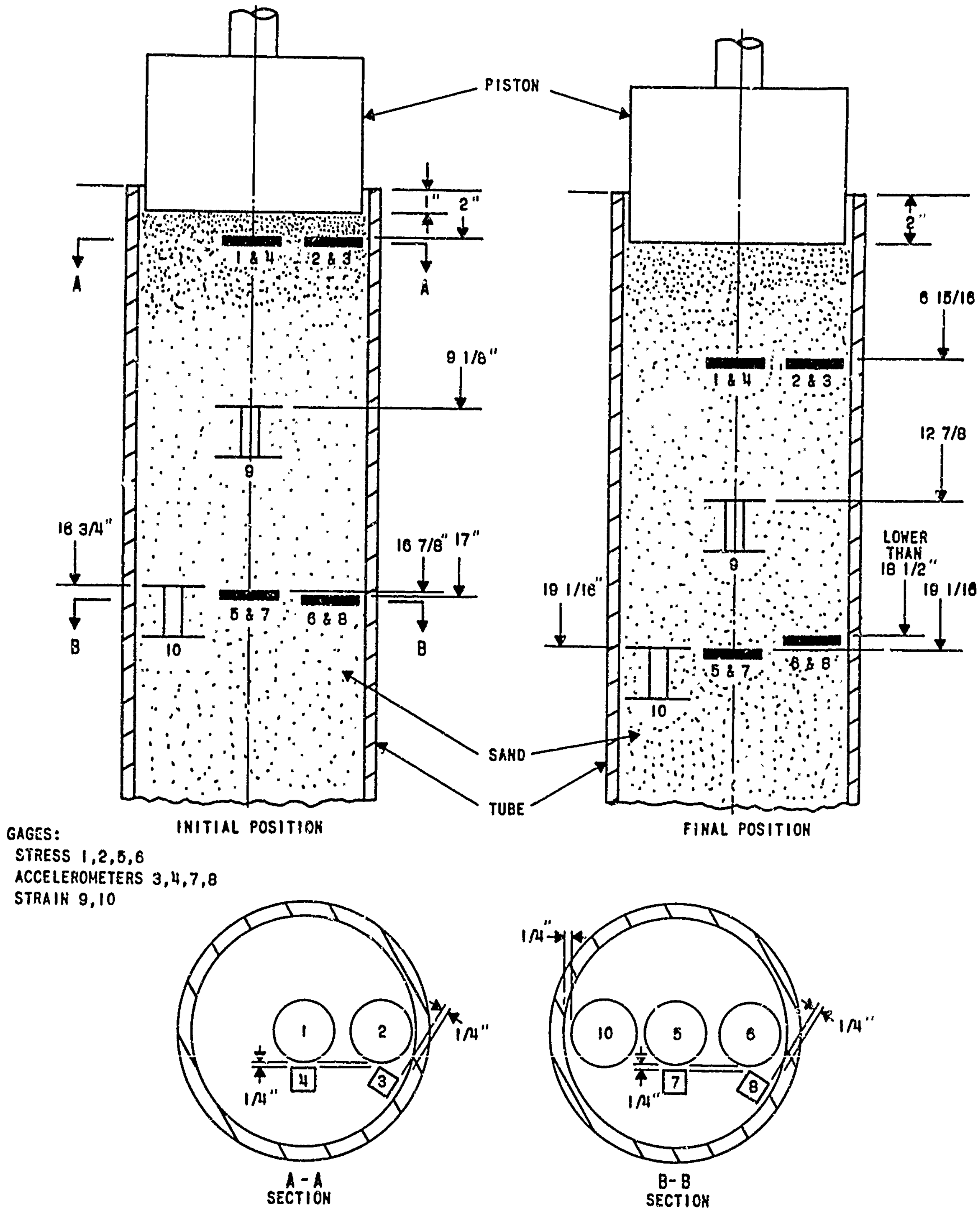


Figure 9. Position of Gages in Test Series Number 2, Group 3.

Each group of tests consisted of a number of successive force applications, and the gage outputs were recorded for each force application. After each of the first few force applications, fresh sand was added to bring the surface back to the original level; otherwise the surface would have been outside the displacement range of the hydraulic cylinders. Sand was not added after the sand column had been compacted to the extent that the piston motion was small, 1/8 inch or so.

Before each shot, the piston was adjusted to be about 1/16 inch above the sand surface. Occasionally the O-ring at the orifice of the Hyge cylinder would not seal properly, with the result that force application would occur slowly instead of suddenly. This condition could be recognized by watching the load cell galvanometer. At a load of about 200 pounds, the pressure was then released, and the Hyge cylinder was readjusted. This event is termed a misfire and is believed to be caused by malfunction of a check valve.

The location of the sand surface with reference to the top of the tube was measured after each shot. The density and moisture content of the sand were not measured.

3.5.3 Observations

3.5.3.1 Stress

Table IX gives the measurements of applied stress and of stress in the sand column during the initial phase of the compaction process, when sand was added before the force application. Measurements are given for the two levels, both at the center and at the edge. During the initial compaction process, stresses observed at the upper level, both at the center and at the edge, were high relative to the applied

TABLE IX

Stress Measurements: Initial Compaction

Test Series No. 2

Note: Sand was added to tube before each of the following applications of force.

Group[1] No.	Shot[2] No.	Applied[3] Stress (psi) Peak	Applied[3] Stress (psi) 100 ms	Stress (psi) Upper Level[4] Center Peak	Upper Level[4] Center 100 ms	Upper Level[4] Edge Peak	Upper Level[4] Edge 100 ms	Lower Level[4] Center Peak	Lower Level[4] Center 100 ms	Lower Level[4] Edge Peak	Lower Level[4] Edge 100 ms
1	2	198	129	306	171	277	150	81	19	59	17
	7	190	145	168	104	246	159	62	14	42	15
2	1	111	44	228	134	236	111	70	37	64	42
	2	174	121	239	197	208	125	55	22	43	26
	3	171	160	190	164	156	144	44	34	32	27
	4	190	185	186	170	166	149	51	43	42	37
3	1	132	76	248	144	250	128	71	36	52	32
	2	202	179	230	186	207	162	41	33	18	18
	3	204	191	212	185	198	167	33	24	18	14

Notes: (1) Between each group of tests, sand was excavated and the tube was filled with fresh sand to a depth of about 27 inches from the top of the tube.

(2) Missing shot numbers represent a recording failure or a misfire.

(3) Force is measured. Stress is computed assuming uniform distribution of force over the area of the piston, 74.6 square inches.

(4) See Figures 2 and 3 for gage locations.

stress. With one or two exceptions, stresses measured at the edge were less than stresses measured at the center.

Table X lists the stress measurements during the final compaction process for the three groups of tests. Sand was not added during these tests. At the upper level, the center peak values were not greatly different from the applied peak stresses, and edge values were usually less than center values. Attenuation between the upper and lower levels is marked.

The oscillograph traces were similar to those shown in Figure 6.

3.5.3.2 Acceleration

The only data taken from the acceleration records were the peak values. These are given in Table XI for the initial compaction phase and in Table XII for the final compaction phase.

3.5.3.3 Sand Surface and Gage Displacement

The displacement of the sand surface caused by each force application is given in Table XIII. Note that sand was added during the early shots of each group.

The initial and final locations of the gages are given in Figures 8 and 9. It is interesting to compare the gage displacement with the sum of the surface displacements.

TABLE X

Stress Measurements: Final Compaction

Test Series No. 2

Note: No sand was added during these tests.

Group[1] No.	Shot[2] No.	Applied[3] Stress (psi)		Stress (psi)							
				Upper Level[4]				Lower Level[4]			
				Center		Edge		Center		Edge	
		Peak	100 ms	Peak	100 ms	Peak	100 ms	Peak	100 ms	Peak	100 ms
1	9	142	145	154	106	176	128	38	20	27	16
	10	143	132	152	114	176	133	41	25	25	17
	11	160	149	177	139	182	136	49	28	29	21
	12	171	151	218	166	191	147	50	25	30	20
2	5	198	196	217	185	164	138	54	41	45	38
	6	218	213	214	195	169	151	59	52	49	45
	7	238	238	242	220	189	168	66	55	59	51
	8	286	264	270	220	258	211	75	52	63	50
	9	338	250	344	238	329	203	91	30	79	34
	10	303	30[illegible]	294	262	262	232	78	62	-	-
	12	352	283	344	256	311	221	99	51	-	-
3	4	246	240	242	210	228	193	37	29	19	16
	5	308	269	318	247	296	220	51	28	27	17
	7	348	325	343	296	336	284	60	39	40	29
	9	409	370	369	278	388	313	67	41	43	32

Notes: See Table IX.

TABLE XI

Acceleration Measurements: Initial Compaction

Test Series No. 2

Note: Sand was added to tube before each of the following applications of force.

Group(1) No.	Shot(2) No.	Applied(3) Stress (psi) Peak	100 ms	Peak Acceleration (g) Upper Level(4) Center	Edge	Lower Level(4) Center	Edge
1	2	198	129	100	97	-	-
	7	190	145	59	41	28	49
2	1	111	44	125	91	82	73
	2	174	121	39	22	19	11
	3	171	160	9	13	8	6
	4	190	185	13	17	12	8
3	1	132	76	87	113	116	92
	2	202	179	14	13	6	8
	3	204	191	13	11	10	11

Notes: See Table IX.

TABLE XII

Acceleration Measurements: Final Compaction

Test Series No. 2

Note: No sand was added during these tests.

Group(1) No.	Shot(2) No.	Applied(3) Stress (psi) Peak	100 ms	Peak Acceleration (g) Upper Level(4) Center	Edge	Lower Level(4) Center	Edge
1	9	142	145	51	38	-	-
	10	143	132	15	15	16	10
	11	160	149	23	15	12	8
	12	171	151	15	11	10	8
2	5	198	196	18	27	10	20
	6	218	213	16	21	16	9
	7	238	238	28	29	17	14
	8	286	264	27	16	13	11
	9	338	250	-	-	-	-
	10	303	300	27	29	24	15
	12	352	283	61	31	29	-
3	4	246	240	27	26	17	14
	5	308	269	69	39	-	-
	7	348	325	41	34	41	42
	9	409	370	56	39	-	-

Notes: See Table IX.

TABLE XIII

Displacement of Sand Surface (inches)

Test Series No. 2

Shot No.	Group 1	Group 2	Group 3
1	2	3	3 1/4
2	9/16 (2)	3/8 (2)	1/4 (2)
3	1/4 (2)	1/8 (2)	1/16 (2)
4	(1,2)	1/8 (2)	3/16
5	(1,2)	1/8	1/8
6	(1)	1/8	1/8
7	3/16	1/8	3/8
8	1/8 (2)	1/8	1/16
9	1/16	3/16	1/16
10	1/16	3/16	
11	1/4	1/8	
12	1/16	1/16	
13	1/16		

(1) Misfires; displacement too small to measure.

(2) Fresh sand added to tube before firing.

	Sum of Surface Displacements (inches)	Stress Gage Displacement, Center, Upper Level (inches)
Group 1	3 4/8	3 1/8
Group 2	4 11/16	4 1/8
Group 3	5	4 15/16

The general trend of these displacements is about what one would expect.

3.5.3.4 Strain

The strain gages were installed with the two discs fully extended. Unfortunately, however, the bridge could not be balanced at this value of the resistance.

3.6 Test Series No. 3: Friction-Reduction System

The purpose of Test Series No. 3 was to test proposed installation techniques and to obtain measurements to assist in the evaluation of the system.

3.6.1 Experimental Arrangement

A four foot long polished stainless steel cylindrical liner was placed in the top portion of the tube. The liner fitted the tube snugly.

A separator was used to install a layer of Teflon powder. The separator is a one foot long, thin-walled cylinder with an outside diameter that is 1/2 inch less than the inside diameter of the liner, leaving an annular space 1/4 inch thick. Four small angles are placed along the outside cylindrical surface, parallel to the longitudinal axis, 90 degrees apart, to maintain the annular separation. All surfaces of the separator were polished with a size 400 grit carborundum paper.

The installation proceeded as follows: The tube was excavated to a depth of 4 feet. The liner was installed. The separator was lowered to the 4-foot depth. The annular gap was filled with Teflon powder No. 5, which was lightly compacted during the filling operation by tapping the tube

with a hammer. The inside of the separator was filled with sand, hand-tamped. The separator was then carefully raised to the next level and the operation repeated until the tube was full. Gages were installed at the selected levels during the filling.

The installation of the Teflon layer was carried out without difficulty. Examination of the layer after the first excavation showed the layer to be uniform and continuous. It was consolidated enough to stand by itself, but a piece broken off could be crumbled easily in the hand.

The initial and final gage locations are shown in Figures 10 and 11. Accelerometers were omitted from the second setup because of the high accelerations observed in the first setup.

3.6.2 Experimental Procedure

Test series No. 3 was carried out in four groups. After Group No. 1 was completed, the setup was left intact over night and force applications, Group No. 2, were continued the next day. The sand and Teflon powder were then excavated to a depth of about 31 inches and a new setup made for Group No. 3. Group No. 4 was a continuation of Group No. 3 after a layover of one night. This procedure was adopted to investigate whether moisture permeating the Teflon layer would cause an observable change.

The procedure for Test Series No. 3 was similar to that described for Test Series No. 2. Whenever column compaction was appreciable, fresh sand and Teflon powder were added.

3.6.3 Observations

3.6.3.1 Equipment Performance

The amplifier attenuations in the first shot were set as for Test Series No. 2, expecting satisfactory traces to be obtained

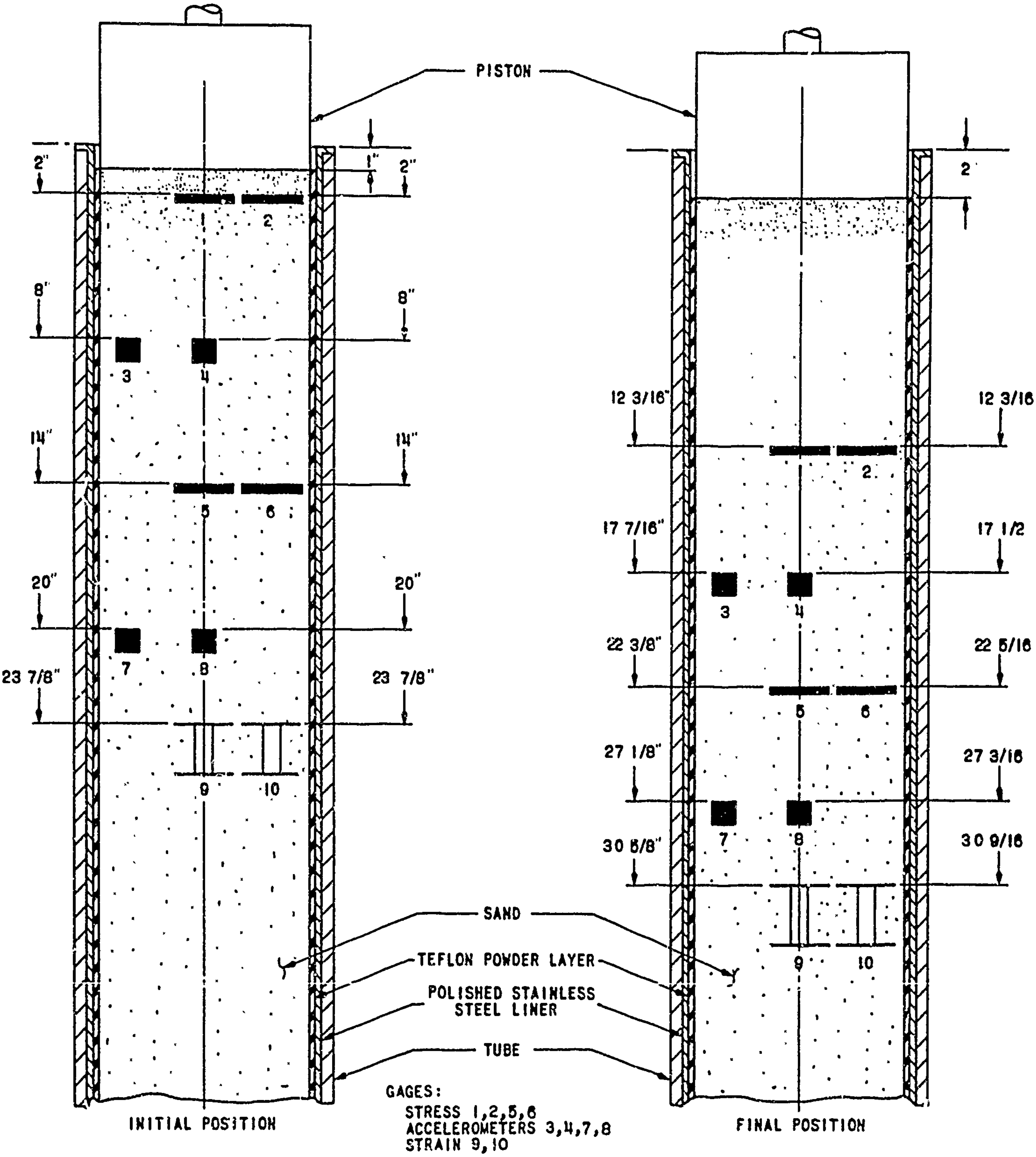


Figure 10. Position of Gages in Test Series Number 3, Groups 1 and 2.

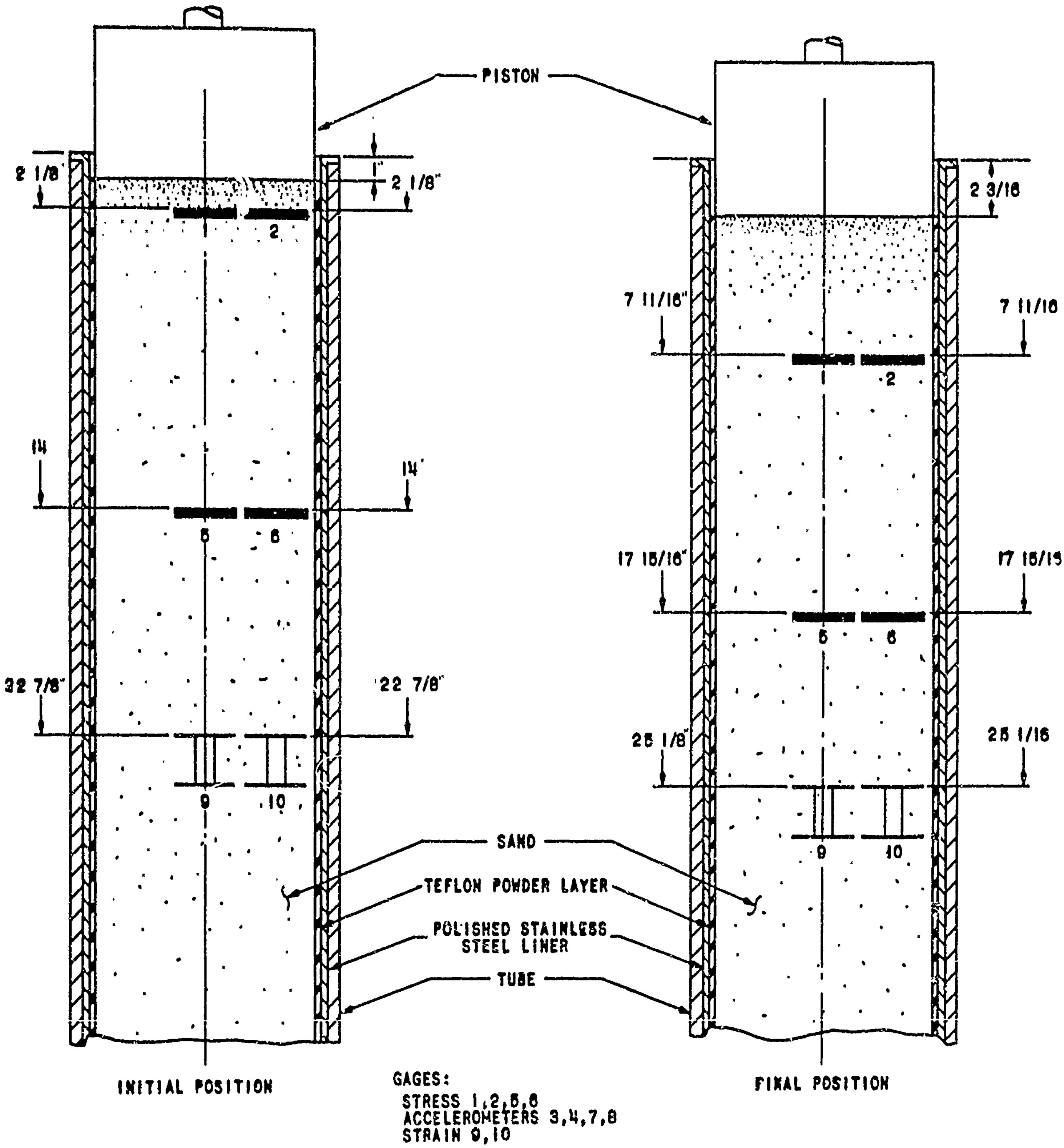


Figure 11. Position of Gages in Test Series Number 3, Groups 3 and 4.

even if transducer outputs were two or three times the previous value. Some of the traces went off the paper, and the attenuation had to be increased. An examination of two or three traces showed amplitudes beyond the range of the gage; so the possibility exists that Test Series No. 3 should be repeated, with different gages or gage locations, to get results which can be compared with the results of Test Series No. 2.

3.6.3.2 Sand Surface and Gage Displacement

The initial and final gage locations are shown in Figures 10 and 11. The displacements of the sand surface in successive shots of Test Series No. 3 are listed in Table XIV. It is to be noted that the surface and the gage displacements are much greater than in Test Series No. 2. At the end of Group No. 2 tests, the upper level gages had been displaced downward 10 3/16 inches, whereas the sum of the sand surface displacements in Group No. 1 and Group No. 2 was 11 11/16 inches. Similar figures for Group No. 3 and Group No. 4 are: gage displacement, 4 9/16 inches; sum of sand surface displacement, 6 13/16 inches. The numerical evidence that compaction occurred to a greater depth is corroborated by the fact that excavation, literally by the hand, was much more difficult between Group No. 2 and Group No. 3 of Test Series No. 3 than between the groups of Test Series No. 2.

Recovery phenomena were observed. With pressure maintained on the sand surface, the distance between the top of the tube and the sand surface was determined. The

TABLE XIV

Displacement of Sand Surface

Test Series No. 3

Shot No.	Group 1 Applied Stress[1] (psi)	Group 1 Displ. (inches)	Group 2[2] Applied Stress[3] (psi)	Group 2[2] Displ. (inches)	Group 3 Applied Stress[1] (psi)	Group 3 Displ. (inches)	Group 4[3] Applied Stress[1] (psi)	Group 4[3] Displ. (inches)
1	136	3 5/8	-	9/16[4][5]	-	9/16[4]	174	7/16[5]
2	174	2 1/2[5]	174	5/16	-	1/16[4]	-	0[4]
3	266	1 7/8[5]	174	0	174	2 1/2	-	0[4]
4	266	1/2	174	1/8	266	1 3/4[5]	174	5/16
5	360	9/16	174	0	360	1/2	183	3/16
6	454	1					183	1/4
7							183	1/16
8							183	1/8
9							183	1/16

Notes:

(1) Applied stress is an approximation estimated from Hyge cylinder operating pressure and Test Series No. 2 data.

(2) Group 2 is a continuation of the Group 1 shock tube setup which was left intact overnight.

(3) Group 4 is a continuation of the Group 3 shock tube setup which was left intact overnight. The sand and Teflon powder were excavated to a depth of about 31 inches after Group 2 and a complete new setup made for Group 3.

(4) Misfire; small static load applied.

(5) Fresh sand and Teflon powder added to tube before firing.

The measurement was repeated after the piston had been removed from the tube. The difference was usually small, but sometimes amounted to 1/2 inch or more. The measurements reported on Table XIV were made after recovery had taken place.

3.6.3.3 Stress

Irregularities were observed in the records of Group No. 4, and it was evident that the ranges of the gages had been exceeded. Two accelerometers were obviously damaged. Laboratory tests of stress-gage performance were made after the field tests were completed. It was found that the stress gages performed satisfactorily in static calibrations but were very sensitive to acceleration. Furthermore, the type of irregularity observed in the records of Group No. 4 could be demonstrated in the laboratory by moving the gages. Hence it was decided to repeat Test Series No. 3 with gages of greater range.

Irregularities were not observed in the records from the first three groups of this test series, and it may be that the readings were valid. Consequently, the observations are reported here in Tables XV-XVIII, but no conclusions will be made until Test Series No. 3 is repeated.

Table XV gives the stress measurements, both the peak and the value at 100 milliseconds, made during the initial compaction of the sand column, when sand and Teflon powder were added to the tube before each force application. Stress measurements made during the final compaction of the sand column, when no sand was added to

TABLE XV

Stress Measurements: Initial Compaction

Test Series No. 3

Friction-Reduction System

Note: Sand and Teflon powder were added to tube before each of the following applications of force.

See text for discussion of gage performance.

		Applied Stress (psi)[3]		Stress (psi)							
				Upper Level[4]				Lower Level[4]			
				Center		Edge		Center		Edge	
Group[1] No.	Shot[2] No.	Peak	100 ms	Peak	100 ms	Peak	100 ms	Peak	100 ms	Peak	100 ms
1	1	58	20	172	70	109	41	58	19	60	20
	2	138	62	-	234	285	191	191	113	162	113
3	3	130	77	375	225	358	204	181	96	182	99
	4	247	182	615	412	386	259	302	217	258	218

Notes: (1) Group 2 is a continuation of the Group 1 shock tube setup which was left intact overnight. The sand and Teflon powder were excavated to a depth of about 31 inches after Group 2 and a complete new setup made for Group 3.

(2) Missing shot numbers represent a recording failure or a misfire.

(3) Force is measured. Stress is computed assuming uniform distribution of force over the area of the piston, 73.6 square inches.

(4) See Figures 10 and 11 for gage locations.

TABLE XVI

Stress Measurements: Final Compaction

Test Series No. 3

Friction-Reduction System

Note: No sand or Teflon powder was added during these tests.

See text for discussion of gage performance.

Group(1) No.	Shot(2) No.	Applied(3) Stress (psi) Peak	Applied(3) Stress (psi) 100 ms	Stress (psi) Upper Level(4) Center Peak	Upper Level(4) Center 100 ms	Upper Level(4) Edge Peak	Upper Level(4) Edge 100 ms	Lower Level(4) Center Peak	Lower Level(4) Center 100 ms	Lower Level(4) Edge Peak	Lower Level(4) Edge 100 ms
1	4	261	188	585	384	-	328	298	215	256	217
	5	302	250	556	392	565	389	334	242	268	242
	6	364	313	720	486	1070	846	412	277	289	267
2	2	181	120	344	215	321	229	181	145	192	154
	3	204	134	384	254	298	244	-	162	-	171
	4	217	152	399	282	302	268	226	166	222	175
	5	171	123	333	235	284	224	171	136	167	145
3	5	348	284	776	585	787	585	375	281	281	268

Notes: See Table XV.

TABLE XVII

Acceleration Measurements: Initial Compaction

Test Series No. 3

Friction-Reduction System

Note: Sand and Teflon powder were added to tube before each of the following applications of force.

See text for discussion of gage performance.

Group[1] No.	Shot[2] No.	Applied[3] Peak Stress (psi)	Peak Acceleration (g)			
			Upper Level[4]		Lower Level[4]	
			Center	Edge	Center	Edge
1	1	58	108	77	23	57
	2	1[illegible]8	66	44	83	83
3	3	130	No accelerometers used in this group			
	4	247				

Note: See Table XV.

TABLE XVIII

Acceleration Measurements: Final Compaction

Test Series No. 3

Friction-Reduction System

Note: No sand or Teflon powder was added during these tests.

See text for discussion of gage performance.

Group (1) No.	Shot (2) No.	Applied (3) Peak Stress (psi)	Peak Acceleration (g)			
			Upper Level (4)		Lower Level (4)	
			Center	Edge	Center	Edge
1	4	261	-	-	-	52
	5	302	-	-	-	127
	6	364	135	200	-	130
2	2	181	-	-	-	-
	3	204	-	-	-	-
	4	217	59	46	-	-
	5	171	52	42	-	-
3	5	348	No accelerometers used in this group.			

Note: See Table XV.

the tube, are given in Table XVI. Acceleration measurements are given in Tables XVII and XVIII. Strain measurements are not reported because the amplifier was overloaded in most cases.

3.7 Earth Shock Tube - Test Series No. 4

Test Series No. 4 was conducted with the assistance of BRL technical personnel.

3.7.1 Experimental Arrangement

The installation and experimental procedure for Test Series No. 3, described previously, was followed in Test Series No. 4. The bottom of the earth shock tube was filled with the building sand used in the previous tests to within 32 inches of the top. Standard Ottawa sand was used to fill the tube to the top. In this test series measurements were made in the Ottawa sand.

Because of the high accelerations noted in the previous tests and the unavailability of higher range, CEC Type 4-202, aluminum-housing accelerometers, accelerations were measured with three Wiancko, Type A1023, accelerometers and one CEC, Type 4-202, stainless-steel-housing accelerometer. A Wiancko accelerometer with a range of 500g was placed at the upper level at the center of the tube and the 250g CEC accelerometer was placed at the edge at the same level for Group Nos. 1 and 2. In Group No. 3, the CEC accelerometer, designated by No. 4 in Figure 12, was placed at the second level at the center of the tube. The other Wiancko accelerometers, with a range of 100g, were used at the lower levels.

The BRL stress gages were reconstructed using CEC, Type 4-313 pressure elements with ranges of 1000 psia and 500 psia. The 1000 psia elements were used at the upper level and the 500 psia elements at the lower level. One of the 1000 psia

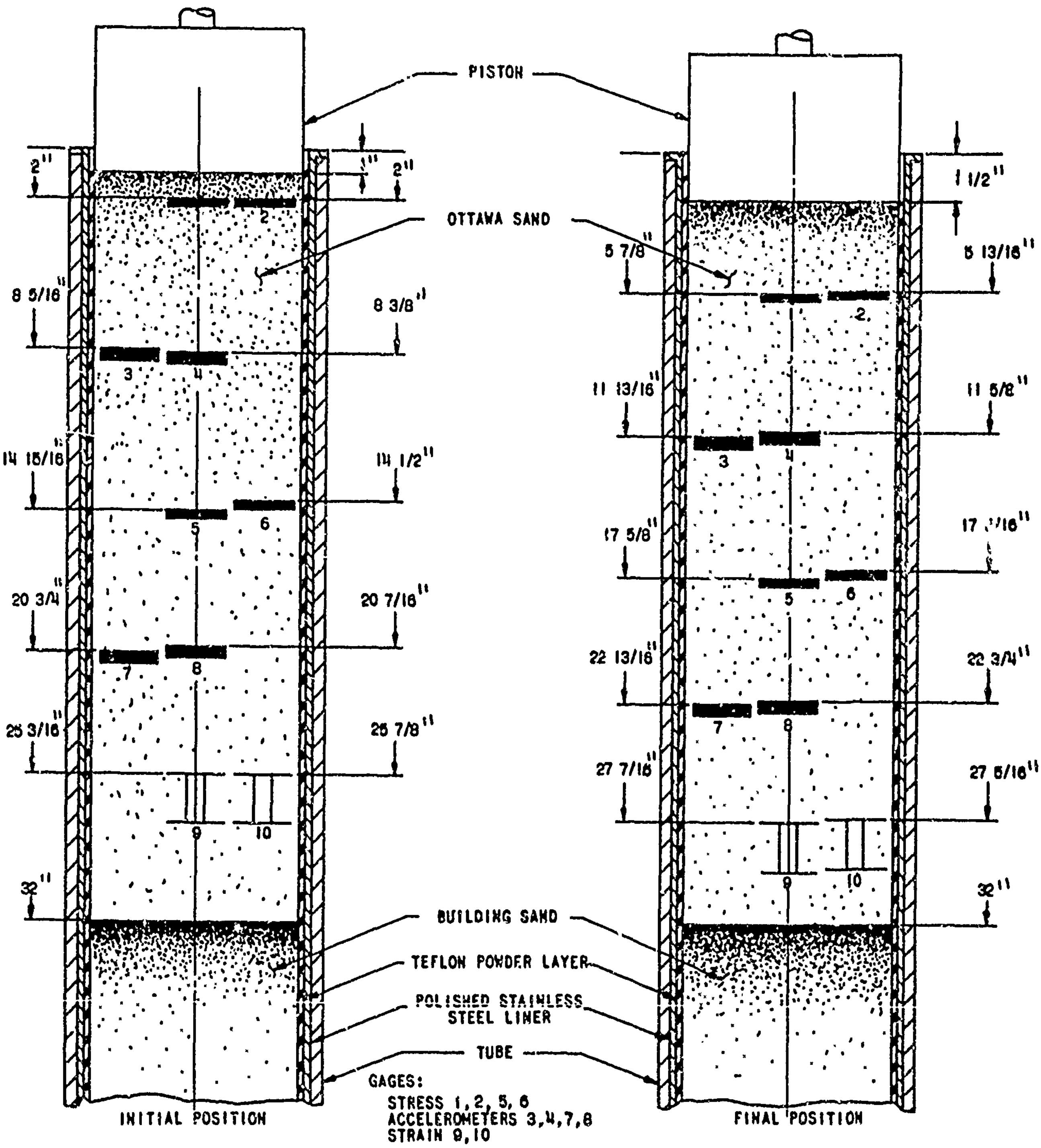


Figure 12. Position of Gages in Test Series Number 4, Group 1.

elements designated as No. 2 in Figure 12, was damaged on the first shot of Group No. 1. The manufacturer informs us that these pressure elements cannot withstand more than 100g's impact loading. Therefore, upon the recommendation of CEC, several Type 4-327 pressure elements, which are capable of withstanding 1000g's for 1 millisecond, are being adapted to the BRL stress gage.

The Atlantic Research Corporation earth strain gage designated as No. 9 in Figures 12, 13, and 14 used the modified bridge circuit to prevent amplifier overloading. The sensitive element of this strain gage was a wirewound linear potentiometer with a resolution of 0.0014 inch. The other strain gage used an infinite-resolution carbon film resistance element as the transducer.

The initial and final locations of the gages for the three groups of tests are given in Figures 12, 13, and 14. In Group No. 1 and Group No. 2, similar gages were placed at the same level, one at the center and one at the edge. Stress Gage No. 2 was damaged, and the bridge could not be balanced for Accelerometer No. 8; so no data are reported for these two gages. In Group No. 3, different types of gages were placed at the same level, as described in Figure 14.

3.7.2 Observations

The experimental arrangements for Test Series No. 4 were different from those for previous tests in the following respects: Ottawa sand was used; the sand was tamped by hand, using a two-inch diameter rod, as the tube was filled and the gages installed; a different metering pin was used for the Hyge Shock Tester, to give faster rise times. Because of these changes, quantitative comparisons of the results of Test Series No. 4 with the results of previous tests may not always be justified.

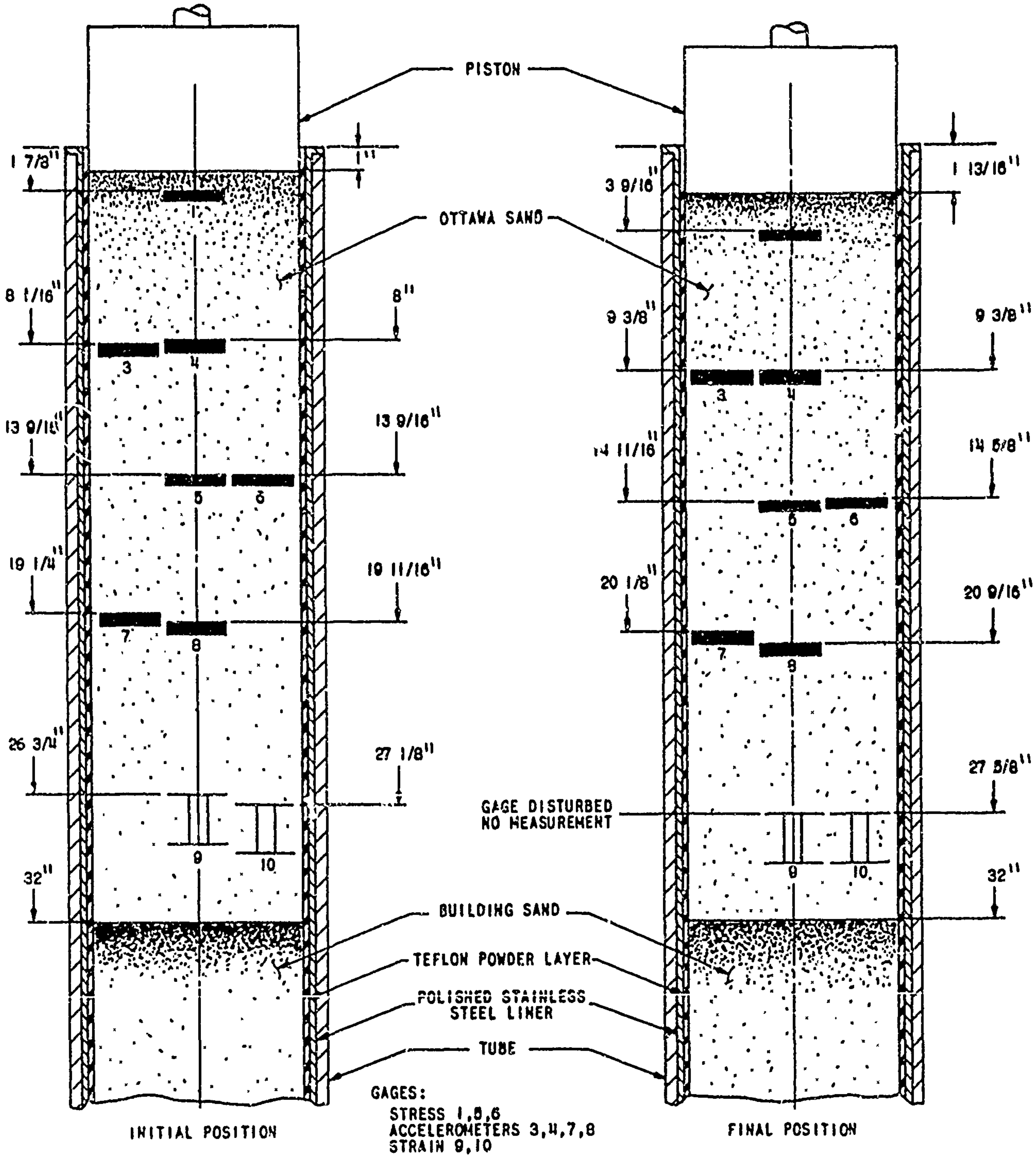


Figure 13. Position of Gages in Test Series Number 4, Group 2.

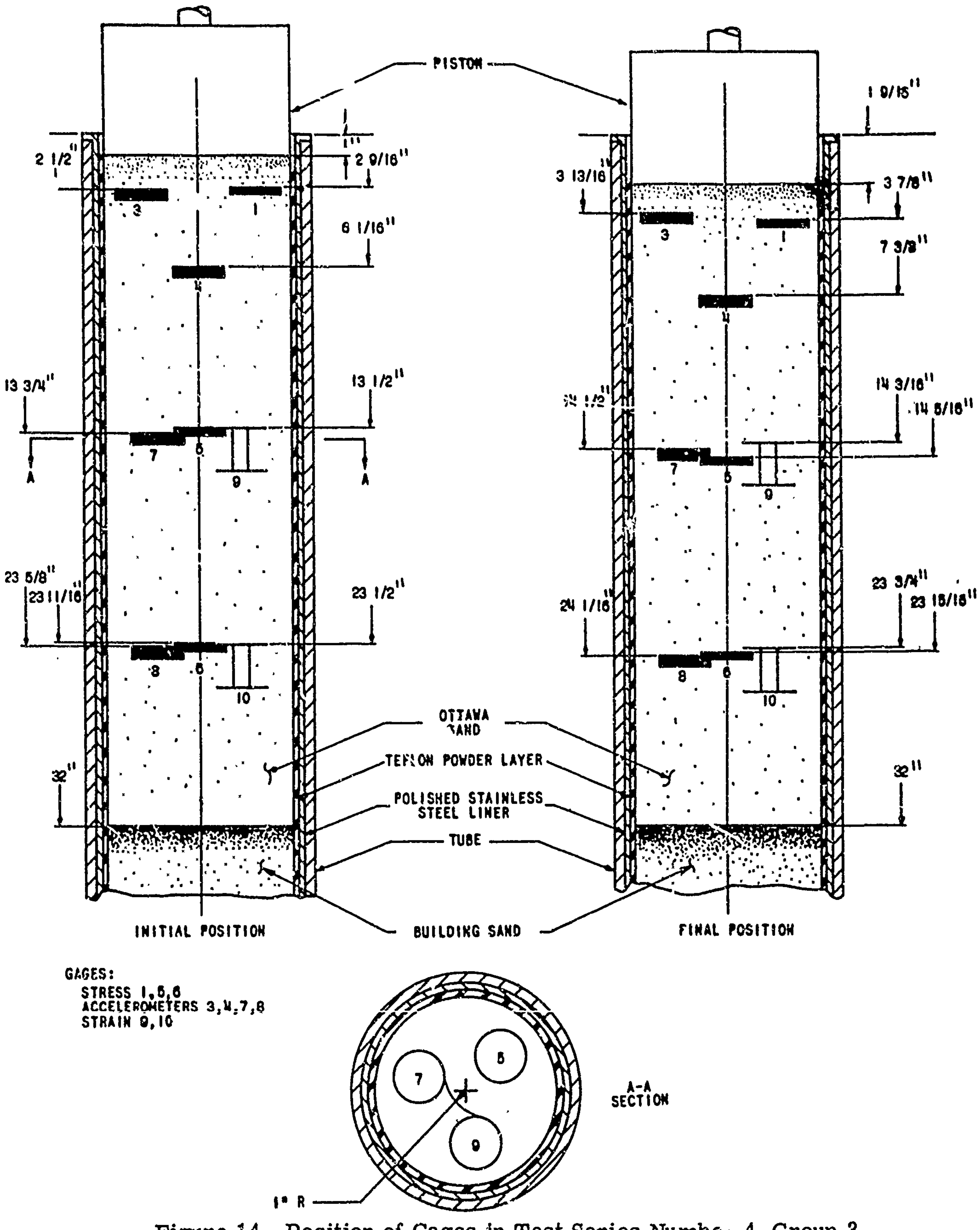


Figure 14. Position of Gages in Test Series Number 4, Group 3.

3.7.2.1 Wave Form

Figure 15 is a tracing of the records given by the load cell, two accelerometers, two stress gages, and a strain gage from Shot No. 13 of Group No. 2. Rise times are much faster than in previous tests, two or three milliseconds for pressure and less than one millisecond for acceleration.

An interesting feature of the pressure records is the pulse which occurs on the otherwise almost flat top of the pressure step. The time of arrival of the pulse at the various gages is consistent with the view that a reflection occurs at the bottom of the liner, four feet down. The sand from the four-foot depth to the ten-foot depth had not been disturbed during the four series of tests, but the whole ten-foot length of the tube was excavated after Series No. 4 in order to relocate the cables. A noticeably compacted layer in the building sand, able to support its own weight over the span of ten inches, was found at the four-foot depth at the bottom of the liner and probably served to reflect the pulse.

During the first few shots of a group, while the sand is being compacted, the wave forms are different from those observed from shots toward the end of the group. Figure 16 is a tracing of records from the first shot of Group No. 2. It will be noted that the rise times are long, ten milliseconds or so for the pressure records and about two milliseconds or so for the acceleration records. A rough indication of the status of compaction seems to be given by the displacement of the sand surface, Table XIX. Speaking generally,

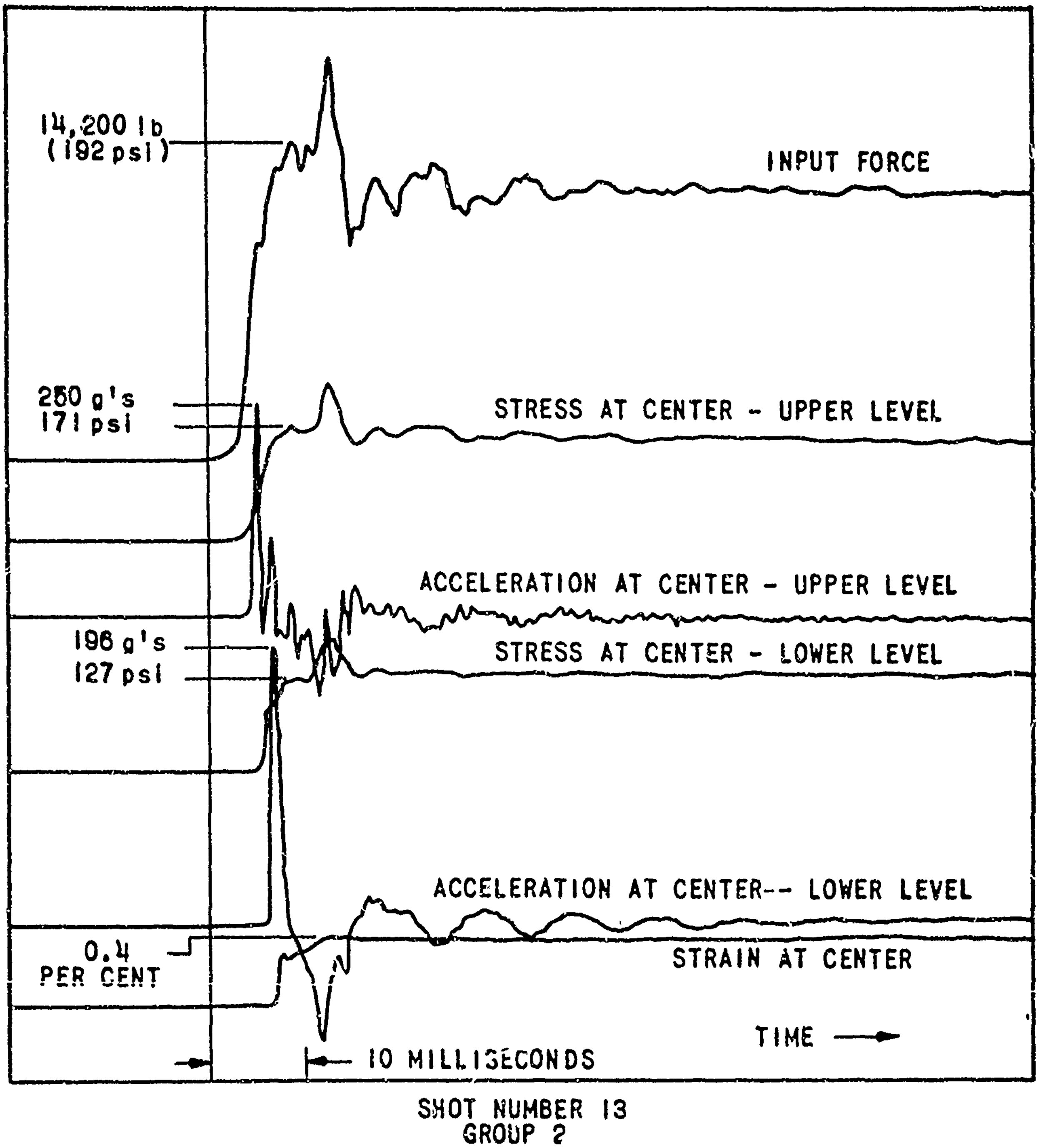


Figure 15. Typical Records from Test Series Number 4 After Compaction.

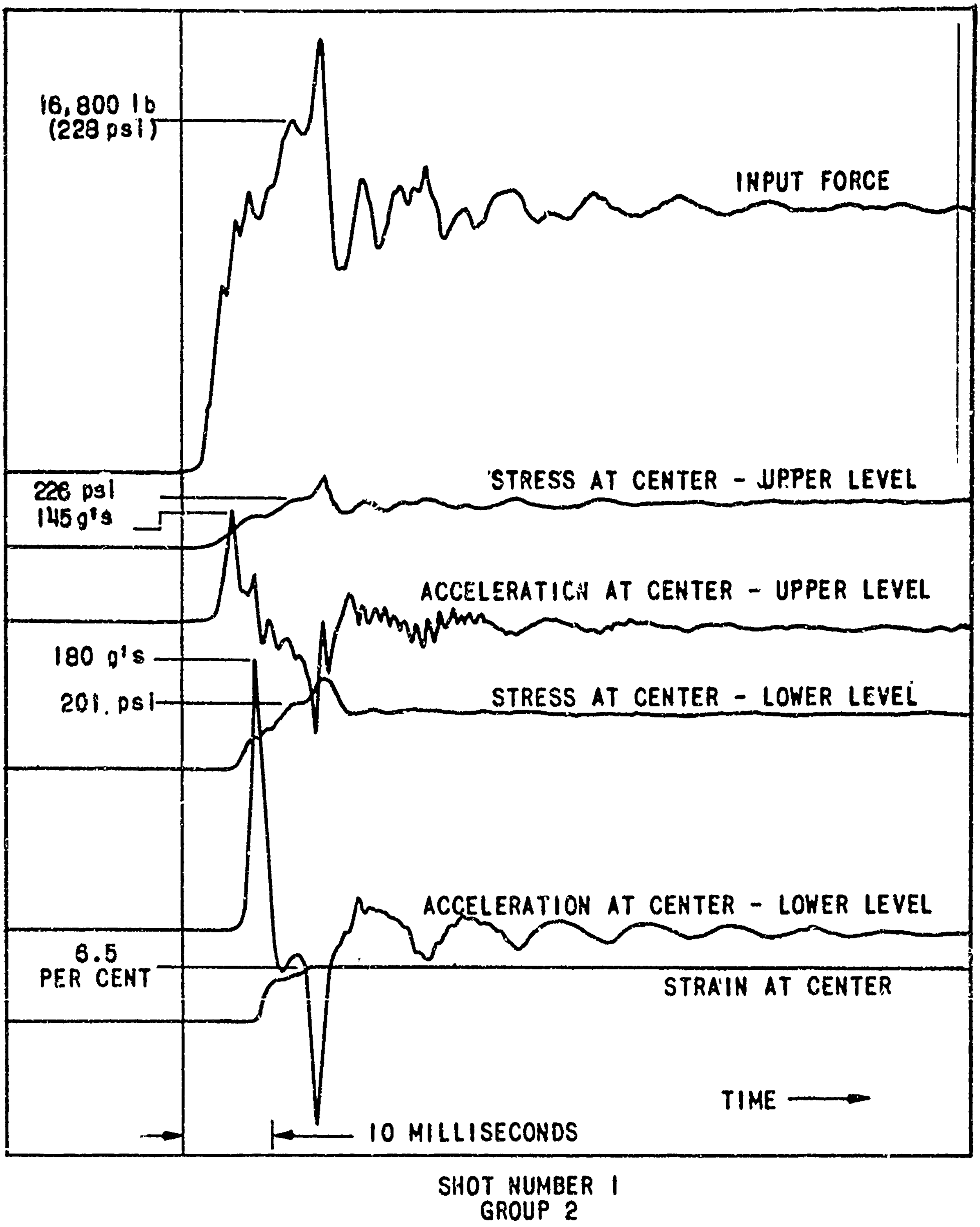


Figure 16. Typical Records from Test Series Number 4 During Initial Compaction.

TABLE XIX

Displacement of Sand Surface

Test Series No. 4

Shot No.	Displacement (Inches) Group 1	Group 2	Group 3
1	1 1/4	5/8	7/8
2	3/8 (1)	1/8	1/8
3	7/16	1/8	3/8 (1)
4	1/8	1/8	1/16
5	7/16 (2)	1/16	1/8
6	1/4 (1,2)	0	
7		1/8	
8		1/4 (1)	
9		3/16	
10		1/8	
11		1/16	
12		0	
13		1/16	
14		1/16 (2)	

Notes:

(1) Sand was added before this shot.

(2) Full tank pressure was applied after the Hyge cylinder fired, and thus a gradually increasing load was applied to the sand column for about eighty seconds. In usual operation, the Hyge cylinder is exhausted right after firing, so that the load on the sand column is reduced in a few seconds.

short rise times are observed when the displacement of the sand surface or successive force applications becomes and remains small.

3.7.2.2 Acceleration

Peak accelerations are recorded in Tables XX and XXI. The accelerations are high, much higher than they were in Test Series No. 2 (building sand, no Teflon powder) or in Test Series No. 3 (building sand, Teflon powder lubricating layer).

In each of the three groups, the acceleration at the lower level is greater than the acceleration at the upper level for the first shots in the group and is less for the last shots of the group. The reason for this apparent anomaly is not evident, although it might be related to differences in the initial state of compaction at the two levels.

The data of Table XX allow a comparison of upper level accelerations at the edge of the tube with the accelerations at the center. Of the 18 pairs of observations, 8 show equal or smaller acceleration at the edge and 10 show greater acceleration at the edge. In Group No. 2, for which all the applied stresses were about 200 psi, the average peak acceleration at the edge was 191g and the average peak acceleration at the center was 181g. It would appear from these average data and from an examination of the individual data that the acceleration of the sand at the the side of the tube is not significantly different from the acceleration of the sand at the center.

TABLE XX

Acceleration Measurements

Test Series No. 4

Group No.	Shot No.	Peak Applied Stress (psi)	Peak Acceleration (g) Upper Level Center	Upper Level Edge	Lower Level Center	Lower Level Edge
1	1	194	137	150	157	140
	2 (1)	286	149	142	139	111
	3	399	570	488	---	154
	4	No records obtained		---	---	---
	5 (1)	198	417	360	216	128
	6	193	115	112	119	85
2	1	228	145	137	180	110
	2	201	136	170	173	115
	3	195	362	335	210	123
	4	195	104	111	137	102
	5	188	99	99	136	102
	6	No records obtained		---	---	---
	7 (1)	183	89	92	131	93
	8	190	167	191	164	115
	9	220	93	97	133	98
	10	208	104	104	148	102
	11	240	316	361	250	127
	12	198	210	222	182	119
	13	192	250	276	196	119
	14	192	275	290	194	123

Notes:

(1) Sand was added before this shot.

TABLE XXI

Acceleration and Stress Measurements

Test Series No. 4

Group No. 3

Shot No.	Peak Applied Stress (psi)	Peak Accel. (g) (1) Gage 3	Gage 4	Gage 7	Stress (psi) (1,2) Gage 1	Gage 5	Gage 6
1	291	159	216	241	458	304	274
2	202	134	135	173	264	164	136
3 (3)	204	144	140	168	319	141	130
4	207	99	107	160	248	136	120
5	204	98	91	84	228	130	120

Notes:

(1) See Figure 14 for gage location; the levels for stress gages and accelerometers were not the same.

(2) See text for discussion of these measurements.

(3) Sand was added before this shot.

In the final four shots of Group No. 2, the amplitude of the acceleration pulse is reduced an average of 21% in traveling from the upper level to the lower level, a distance of 11 3/16 inches.

3.7.2.3 Stress

Stress measurements are reported in Tables XXI and XXII. In most cases the value reported was that of the plateau before the peak, because the peak was taken to be a reflection. For a few of the early shots in a group, the peak was reported, because the rise was continuous and smooth without any indication of a plateau.

The stresses reported at the upper level for Group No. 1, Group No. 3, and two shots of Group No. 2 were greater than the applied stress. Similar inconsistencies occurred in the values reported for the lower level. The explanation for these anomalies is not yet apparent, although it is believed that they cannot be attributed to faulty calibration of the gages or the recording system.

Certain dynamic effects on the gages can be expected. Inertial effects of a moving column of sand would increase the recorded pressure, and this might be particularly important during the compaction process. The transducer is sensitive to acceleration. According to the manufacturer, the acceleration sensitivity is 0.05% of full range per g. At accelerations of 100g, this effect might be significant, as much as 50 psi for the gages at the upper level and 25 psi for the gages at the lower level. Correction has not been attempted for acceleration sensitivity, because the accelerometers were not at the

same level as the stress gages (except for Group No. 3). Errors of dynamic origin would be a maximum during the first one or two milliseconds of a record and may not be important for the stress data given in the table (except, possibly, during the early stages of compaction).

The static recordings of the stress gages are probably also in error, or, better said, are probably not representative of the undisturbed medium. The stress values at 100 milliseconds given for Test Series No. 3 are inconsistent with the values reported for the applied stress. Similar anomalies were found in the one or two static measurements (not reported) made in connection with Test Series No. 4. Clearly, the characteristics of the stress gages should be investigated further.

Although the numerical values of the stress are questioned, relative values may give valid information. The data of Table XXII allow a comparison of stress at the edge with stress at the center, both at the lower level. Of the 18 pairs of observations, 8 show the stress at the edge to be equal to or less than the stress at the center and 10 show the stress at the edge to be greater than the stress at the center. In Group No. 2, for which all applied stresses were about 200 psi, the average of the stress readings at the edge is 158 psi and the average stress at the center is 155 psi. We conclude that stress measured at the edge is not significantly different from stress measured at the center.

TABLE XXII

Stress Measurements

Test Series No. 4

Group No.	Shot No.	Peak Applied Stress (psi)	Stress (psi) (1) Upper Level Center	Lower Level Center	Lower Level Edge
1	1 (2)	194	214	284	268
	2	286	424	309	300
	3	399	459	388	393
	4	No records obtained		---	---
	5 (2)	198	223	149	157
	6	193	234	126	130
2	1	228	226	201	221
	2	201	194	151	168
	3	195	153	143	153
	4	195	182	301	293
	5	188	225	142	141
	6	No records obtained		---	---
	7 (2)	183	103	135	135
	8	190	212	127	129
	9	220	157	139	137
	10	208	146	140	132
	11	240	195	150	151
	12	198	157	132	133
	13	192	171	127	132
	14	192	149	126	123

Notes:

(1) See text for discussion of these measurements.

(2) Sand was added before this shot.

In the final four shots of Group No. 2, the amplitude of the recorded stress step is reduced an average of 20% in traveling from the upper level to the lower level, a distance of 11 1/8 inches. The stress attenuation is thus approximately equal to the peak acceleration for these four shots. Additional evidence regarding attenuation is given by the fact that the amplitude of the reflected stress pulse, when it returns to the upper level after a travel of 7 1/2 feet, is 30% to 40% of the amplitude of the incident stress step (also measured at the upper level).

3.7.2.4 Strain

A sequence of satisfactory strain records was obtained, for the first time, in Group No. 2 of Test Series No. 4. The peak strains are given in Table XXIII.

The quantity actually recorded is the change in distance between the two discs, which is converted to strain by dividing by the actual distance between the discs. The distance between the discs was not measured before each shot and cannot be computed from the observed change in distance because of the recovery which takes place when the force applied to the sand is removed. In Table XXIII the base length is assumed to be the maximum distance between the discs, and the actual strains may be up to 1/5 greater than those reported.

The resistive transducer in the center location was wire-wound with an advertised resolution of less 1.4 mils. The transducer at the edge location was a carbon film with a resolution claimed to depend only on the amplifying and recording equipment. The

TABLE XXIII

Approximate Strain Measurements (1)

Test Series No. 4 - Group No. 2

	Peak Strain (percent)	
Shot No.	Center	Edge
1	6.5	3.2
2	2.8	1.8
3	2.5	1.5
4	0.8	1.4
5	0.6	1.4
6	---	---
7	0.5	1.3
8	0.6	1.4
9	0.5	1.2
10	0.5	1.2
11	0.6	1.4
12	0.5	1.0
13	0.4	1.0
14	0.5	1.0

Notes:

(1) The maximum distance between the discs of the Atlantic Research strain gage was used as the base length for computing the strain. Therefore, excluding Shot No. 1, these data can be in error by a maximum of 20% of the reported strain.

smallest observed change in distance was ten mils; so resolution errors can be no greater than 14%.

The form of the strain wave front is often similar to the form of the stress wave front; most of the strain occurs in the first millisecond, and a gradual increase up to the final value occurred during the next several milliseconds. Table XXIII records the final value. According to these data, strain at the edge is less than strain at the center during initial compaction but becomes greater as compaction proceeds. Additional measurements in future work will be necessary to check this first set of strain observations.

3.7.2.5 Conclusions

Measurements of acceleration made in the earth shock tube with the Teflon powder lubricating layer are much higher than accelerations measured in the earth shock tube, and the attenuation of stress and acceleration is reduced. Measurements of stress and acceleration at a given level are approximately the same whether made at the edge or at the center.

Readings of the stress gages appear to be anomalous and further investigation is required. A series of strain records has been obtained, but additional work is necessary to test the gage and to develop the technique of using it.

3.8 Additional Proposed Test Series

Since the Teflon powder friction-reduction system seemed to have achieved a measure of success, plans were made to extend the system to the full 10-foot length of the shock tube. In addition, provisions were made to measure the frictional force at the sidewalls of the confining tube

during each application of force (Figure 17).

If these measurements had been attempted, they may have established what fraction of the applied energy was lost as friction.

Another series of earth shock tube tests was conducted. In this test series, the Teflon powder friction-reducing system was placed in the entire length of the 10 foot shock tube.

The data seemed to indicate that the friction-reducing technique did not perform as expected. However, further investigation revealed that the Teflon powder layer between the sand column and the confining tube was not continuous. There were several large areas in the tube, especially at approximately 55 inches from the top of the tube, where no Teflon powder was present and the sand came into direct contact with the confining tube. The total contact area was considered to be of sufficient size and so oriented that the friction-reducing technique could not be evaluated. Therefore, the data obtained from this series of tests will not be reported and the series should be repeated.

A new technique, using electric vibrators, was proposed to introduce the Teflon powder between the sand and the confining tube. A series of tests utilizing this procedure was never carried out.

3.9 Additional Instrumentation Testing

In tests with the earth shock tube anomalously high readings were reported from stress gages imbedded in the soil under both static and dynamic conditions. This over-registration of earth pressure cells is found in the static and quasi-dynamic measurements of soil mechanics(1) and has recently been reported(2) in dynamic soil measurements similar to those

(1) See, for example, the following summary paper: J. J. Hamilton; Earth Pressure Cells, Design, Calibration and Performance; National Research Council (Canada), Division of Building Research, Technical Paper No. 109; Ottawa, November 1960.

(2) T. Winston and J. R. Stagner; Free-Field Stress Gauge and Test Results in a New 1000 psi Dynamic Pressure Tank; Noise Control, Shock and Vibration, 7, 4-10 (November-December 1961).

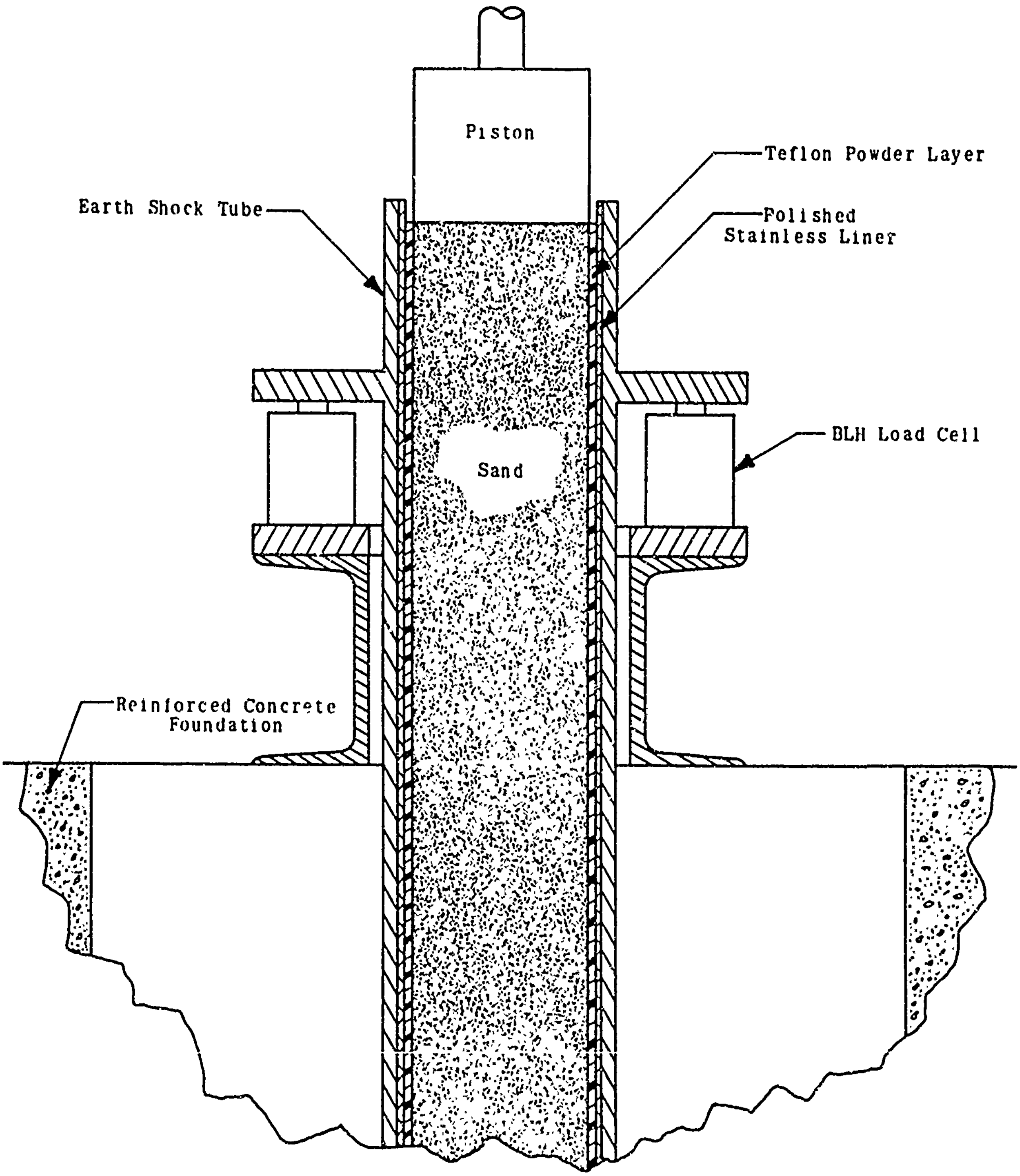


Figure 17. System to Measure Friction at Sidewall of Earth Shock Tube.

made in this project.

A series of simple preliminary static tests was conducted at the Ballistic Research Laboratories, observed by Atlantic Research Corporation personnel, to investigate stress gage behavior in sand. Several stress gages similar to those used in our dynamic tests were imbedded at several levels in a container of ordinary sand. The container was approximately 12 inches in diameter and 2 feet high. The top gage was placed approximately 1/2 inch below the top surface of the sand. A load was applied to the confined sand by means of a piston loaded with a manually-operated hydraulic system. A load cell placed between the piston and the hydraulic actuator measured the applied load. Some of the general observations made during these tests are reported here, by permission of the BRL Technical Supervisor.

It was found that the imbedded stress gages could be made to register any value, within the limits of the system, by simply adjusting the sand density about the active face of the stress gage. When a small mound of sand was placed above the stress gage, as shown (exaggerated in Figure 18(A), the application of force to the sand column produced high stress indications by stress gages 1 and 3. If a small depression was made over the stress gage, as shown (exaggerated) in Figure 18(B), the stress gages would indicate low stresses, and in some cases very nearly zero stress, for maximum input stress. After each test, the piston was carefully removed from the container and the top sand surface observed. The surface was flat, and there was no indication that an irregularity had been present on the surface.

It is obvious from these tests that stress gages imbedded in sand can indicate values which are not in agreement with the average input stress. Therefore, an investigation of stress gage behavior in soils was undertaken to determine if reliable stress measurements can be made with imbedded gages.

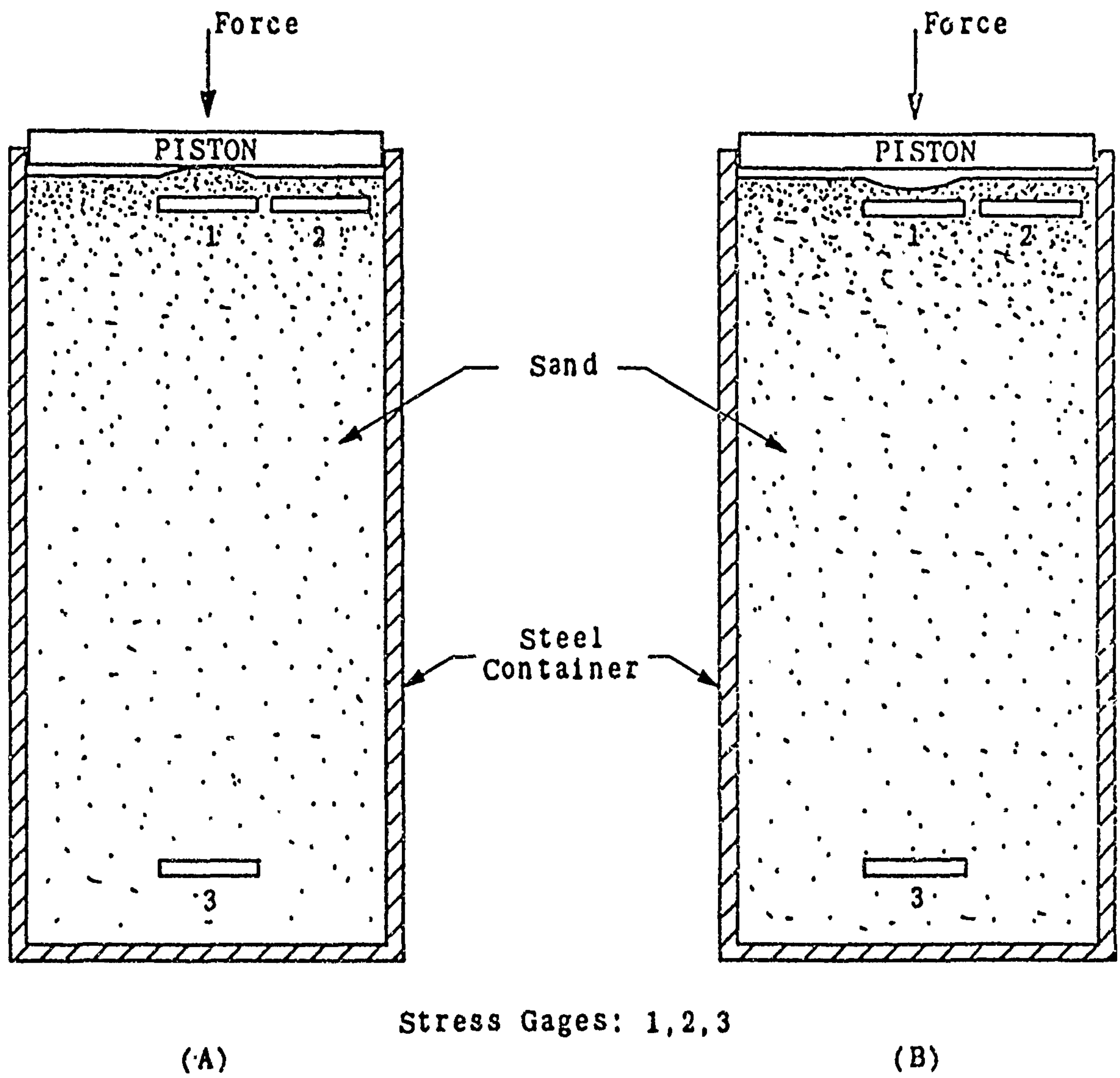


Figure 18. Experimental Arrangement for Static Tests to Observe Stress Gage Behavior in Sand.

4.0 DYNAMIC OEDOMETER

It was evident from earlier shock tube tests that the imbedded stress gages measured anomalously high values of stress under both static and dynamic conditions. This over-registration of earth pressure cells is not uncommon in soil measurement programs; however, the phenomenon is not quantitatively understood. Therefore, it was decided to extend the program to investigate soil compaction and imbedded stress gage behavior before further shock tube tests were carried out. To carry out this program, a laboratory device was designed by Atlantic Research Corporation under the direction of Dr. Werner Heierli and Dr. Alva Matthews of the Paul Weidlinger Consulting Engineering Firm. This device, named the dynamic oedometer by Dr. Heierli, was designed to be used in experiments on constrained soil samples subjected to one-dimensional loading. In addition to the stress gage investigation program, it is hoped that experiments may be conducted to determine accurate values of Poisson's ratio, constrained modulus and other soil constants useful for propagation predictions.

The dynamic oedometer is a laboratory device designed for the investigation of soil compaction and embedded stress gage behavior. It was expected that the device would be useful in one-dimensional wave propagation studies. A cross section of the device is shown in Figure 19 and a photograph of the assembled unit is shown in Figure 20. This device is designed for a 1,000 psi maximum input pressure pulse.

4.1 Design

4.1.1 General

The dynamic oedometer is very similar to the device used for static tests. However, the rate of load application in this device can be controlled from a very slow rate, essentially a static load, to a very rapid rate, depending upon the loading device. It was planned to use the pneumatic device, the "Hyge" unit as a force applicator. This unit was described briefly in paragraphs 3.2 and 3.3 of this report.

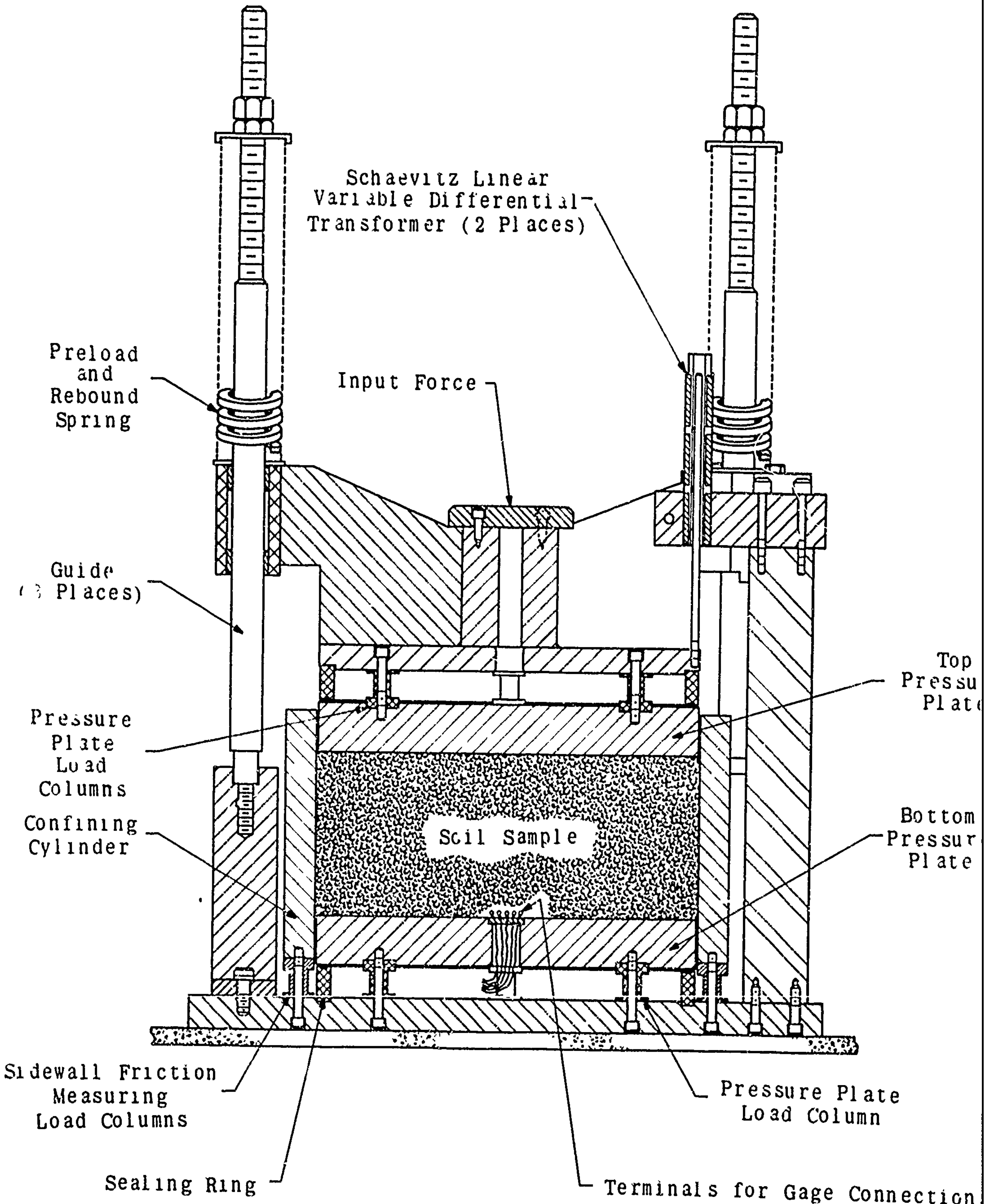


Figure 19. Cross Section of Dynamic Oedometer.

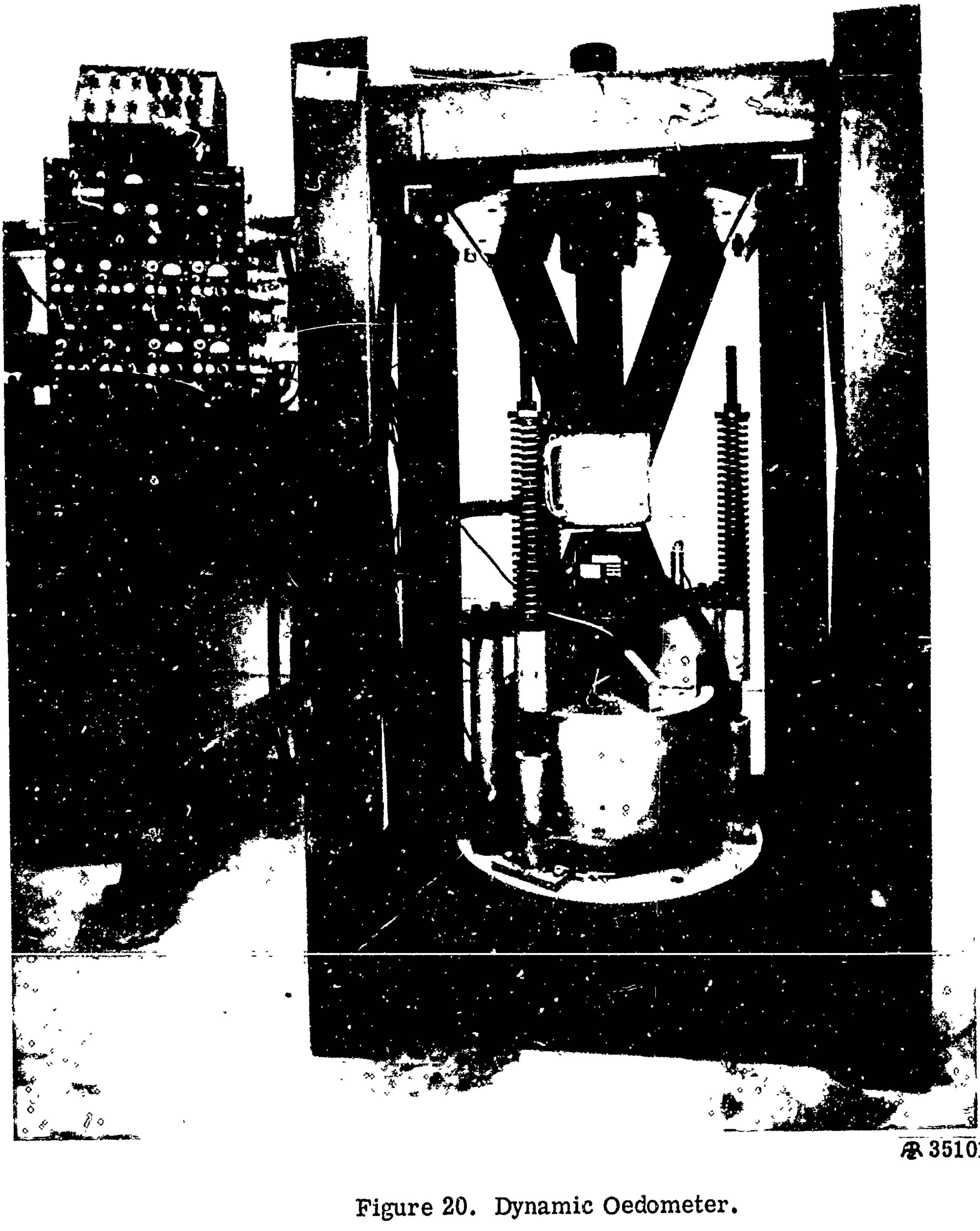


Figure 20. Dynamic Oedometer.

The Hyge unit is capable of producing peak forces of 40,000 pounds with a rise of time of a few milliseconds.

The oedometer consists of three main members - the confining cylinder and a top and bottom pressure plate. The soil sample is packed in the very rigid smooth confining cylinder which allows essentially no lateral deformation. The sample is further confined by the top and bottom pressure plates as shown in Figure 19. A pressure pulse is introduced into the sample through the guided top pressure plate. The displacement of this plate is measured by two diametrically opposed Schaevitz LVDT gages. The input pulse is measured both by the load column arrangement in the top plate and a Baldwin Lima Hamilton load cell which is located between the source and the top plate assembly. As the pressure pulse passes through the sample, it is measured by the load columns located in the bottom pressure plate assembly which is identical to the top plate arrangement.

The movement of the top pressure plate is guided by three equally spaced guide rods. The arms extending from the plate to the guide rods contain oilite bushings which minimize the frictional force on these moving members. To either preload the soil sample or to control to some degree the rebound of the top pressure plate, a coil spring is used at each guide rod.

It is expected that with a soil sample of a height-diameter ratio of 1/4, the side friction between the soil and the confining cylinder can be reduced to a negligible amount. However, to establish the exact side friction-time history during a test, the confining cylinder is supported by four equally spaced load columns which are instrumented with strain gages.

Extremely small circumferential strains in the cylinder which are assumed not to affect the soil measurements will be measured by strain gages placed

in two diametrically opposed longitudinal grooves in the cylinder wall.

An important requirement of the dynamic oedometer is that the state of stress in the soil sample during a test should be quasistatic; i.e., that at any one time during the dynamic loading of the sample, the stresses within that sample must be the same for different locations. One of the initial tests planned for the device is to determine whether or not such a quasistatic condition exists.

4.1.2 Pressure Plates

The average pressure at the top and bottom of the soil sample is measured by identical arrangements of a pressure plate supported by four equally spaced load columns. The plates which form part of the pressure plate assembly are designed to have sufficiently small deflections and a high natural frequency. Calculations show that the plate supported by the four load columns will have a maximum deflection in the order of 1/2000 of the diameter. The natural frequency of the pressure plate and the supporting load columns is in the order of 3200 cps.

Also, to minimize the effect of inertial forces due to the acceleration of the top pressure plate, it was constructed of an aluminum alloy. Assuming a 1000 psi peak pressure input into the sample with a rise time of 4 milliseconds and a parabolic deflection of the soil, calculations show the inertial loss due to the mass of the plate is in the order of 25 psi. As can be seen in Figure 19, the mass above the supports does not influence this inertial pressure loss.

To facilitate electrical connections to imbedded stress gages, a terminal arrangement consisting of a Teflon plug and wire pins is inserted into the bottom pressure plate. To eliminate any interference between the movement of soil particles and the Teflon plug, it is mounted flush with the pressure plate surface.

To eliminate additional frictional forces due to soil particles jamming between the pressure plates and the confining cylinder, the clearance between these two members is in the order of several thousandths of an inch which is smaller than the grain size of the proposed samples.

4.1.3 Load Columns

The average pressure at the top and bottom of the soil sample and the side frictional load on the confining cylinder are measured by load columns. These load columns are instrumented with standard resistive foil elements which are connected in a Wheatstone bridge arrangement. Due to the maximum input pressure of 1000 psi and the low sensitivity of foil strain gages, two sets of load columns for the top and bottom pressure plates were considered. A small diameter cylindrical spool type load column is used for the lower stress levels while a solid cylindrical column is used for the higher stress levels. Piezoresistive strain elements were considered to instrument the columns because of their high gage factor; however, it was decided that their high temperature coefficients would produce many drift problems.

Load columns which were used were made of 15-7 Mo wrought stainless steel. They were heat treated to a hardness above Rockwell 40C and a tensile strength of 210,000 to 240,000 psi.

Special Constantan foil strain elements (Dentronics No. MH234TT-C6) possessing low hysteresis and high linearity characteristics were attached to each load column with RP-43 cement and cured for one hour at 350°F. Electrical connections were made to the foil elements and a gage coat of RP-43 was applied. The assembly was then post cured at 350°F for 24 hours.

Each instrumented load column was cycled with compressive loads twelve times with a Tinius Olsen testing machine. The peak force was 15,000 pounds. Three of the fourteen columns exhibited open circuit gages after testing and had to be reconditioned. A check on the linearity and hysteresis of the gage elements after testing indicated that they were still within the manufacturer's specifications.

The foil elements were then potted in a RTV silicone rubber compound to minimize the temperature drift problems.

The load columns supporting the confining cylinder which are used to measure the side friction are identical in design to the columns used in the pressure plates.

To eliminate the introduction of foreign matter into the top and bottom pressure load column cavity, a sealing ring is inserted between the pressure and the back-up plate. This ring is also used to offer some shielding to the unshielded strain gage leads.

4.1.4 Cylinder

The steel cylinder used to confine the soil sample has the following dimensions: 12-inch inside diameter, 1-inch wall thickness, and 7 3/4-inch length. It is sufficiently rigid to give a practically constrained test. Calculations, based upon the postulate that the lateral strain in the soil sample in the oedometer should be no more than 1/500 of the lateral strain of the soil in a confined test, indicate that the circumferential strain will be in the order of 0.01×10^{-3} in/in for each 100 psi increment of axial stress. This amount of strain is considered to be satisfactory for the contemplated tests.

Since an attempt was to be made to determine the dynamic Poisson's ratio of the soil sample, it was desirable to incorporate into the design of the cylinder a method of measuring this small circumferential

strain. A strain gage attached to the cylinder wall would produce too small an output to be useful; therefore, to produce stress concentrations in the cylinder to produce sufficient gage output, two sets of diametrically opposed grooves are incorporated into the cylinder design. The grooves are placed longitudinally on axis, both from within and without the cylinder in a symmetrical arrangement so as to preserve the neutral axis. Therefore, using narrow grooves and assuming that the material behaves elastically, there will be no deformation from the circular shape of the cylinder. To produce a smooth surface on the inside of the cylinder, the grooves are filled with Araldite and machined to the inside diameter of the cylinder. The araldite has a low modulus of elasticity compared to that of steel. Strain gages are cemented into both outside grooves in the loaded area of the cylinder. Since the cylinder is loaded on only part of its length, careful consideration had to be given to detailed calibration of the strain gages placed in the grooves before accurate Poisson's ratio measurements can begin. A calibration technique similar to the actual loading of the cylinder must be used.

The natural frequency of the cylinder for cylindrically symmetrical vibrations (breathing mode) (neglecting the grooves) is 4600 cps.

4.1.5 Pressure Input

Initially a pneumatic loading device, the "Hyge" unit used on the earth shock tube was selected to be used as the force applicator for the dynamic oedometer. The Hyge unit allows peak forces up to 40,000 pounds with a rise time of about 4 milliseconds to be applied to the oedometer.

4.1.6 Friction Problems

If side friction measurements indicated excessive values, it would become necessary to introduce a friction reducing system (such as silicone grease,

Teflon powder, etc.) between the soil sample and the confining tube.

Also, tests of friction between the soil sample and the pressure plates should be made. Friction on these end plates would greatly influence the lateral pressure measurements. If tests indicate that excessive friction is present on these plates, friction reducing systems will be incorporated into this area.

4.2 Testing

The dynamic oedometer was statically calibrated to a maximum force of 50,000 pounds.

No further work on the oedometer was performed under this contract.

The experiments run in the dynamic oedometer were funded under Contract No. DA 18-001-AMC-877X. A final report on this program has been incorporated as Part II of this report.

5.0 HORIZONTAL DISPLACEMENT METER

5.1 Development

This instrument was originally conceived by personnel of the Ballistics Research Laboratories at the Aberdeen Proving Ground[1]. A laboratory model was constructed at Aberdeen Proving Ground to demonstrate the principle. Atlantic Research Corporation was selected as contractor under Contract Number DA-36-034-ORD-3116-RD, a then existing contract, to design, fabricate and laboratory-test an instrument embodying those principles demonstrated that would be suitable for field application and routine manufacture. Atlantic Research initiated design work on this project in June of 1962. Design goals for the instrument housing dictated that it be watertight and have the structural strength to withstand the pressure and shock environment expected in association with 6-inch displacements in rock and soils. Intimately related to the housing design is the mechanism for precisely leveling the instrument in the longitudinal direction (propagation path of expected displacement wave) after it has been firmly imbedded at the test station. The housing design employed two concentric cylinders. The outer cylinder, shown in Figure 21, provides protection from environmental damage and the inner cylinder; Figure 22, provides a structural base for the working parts of the seismometer. The inner cylinder is mounted to the outer cylinder at three points, Figure 22. Two of these points are designed to transmit about 99 percent of the acceleration loading due to the expected shock. These two points are located on the central horizontal diameter of the cylinder and use ball bearings to support the inner cylinder assembly. The third point which is designed to transmit about 1 percent of the inertial loading is a steel tongue attached to the inner cylinder with an electrical heating element wrapped around its periphery that is electrically and thermally insulated from the tongue, but is mechanically bonded to it. This projects into a cup attached to the outer cylinder. This cup

(1)Patent 3, 164, 983, B. Perkins, Jr., et. al., Horizontal Displacement Meter.

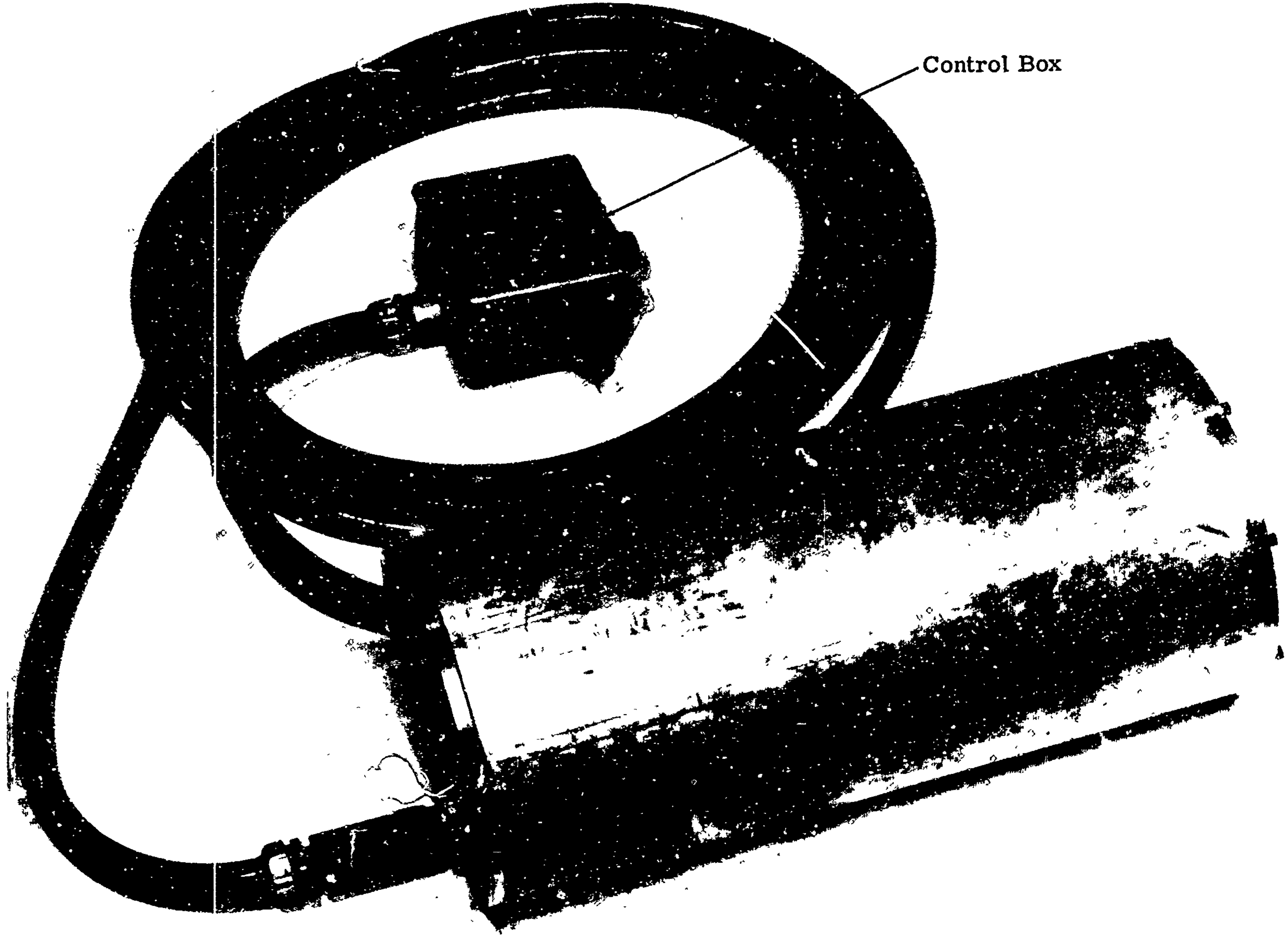


Figure 21. Horizontal Seismometer Assembly.

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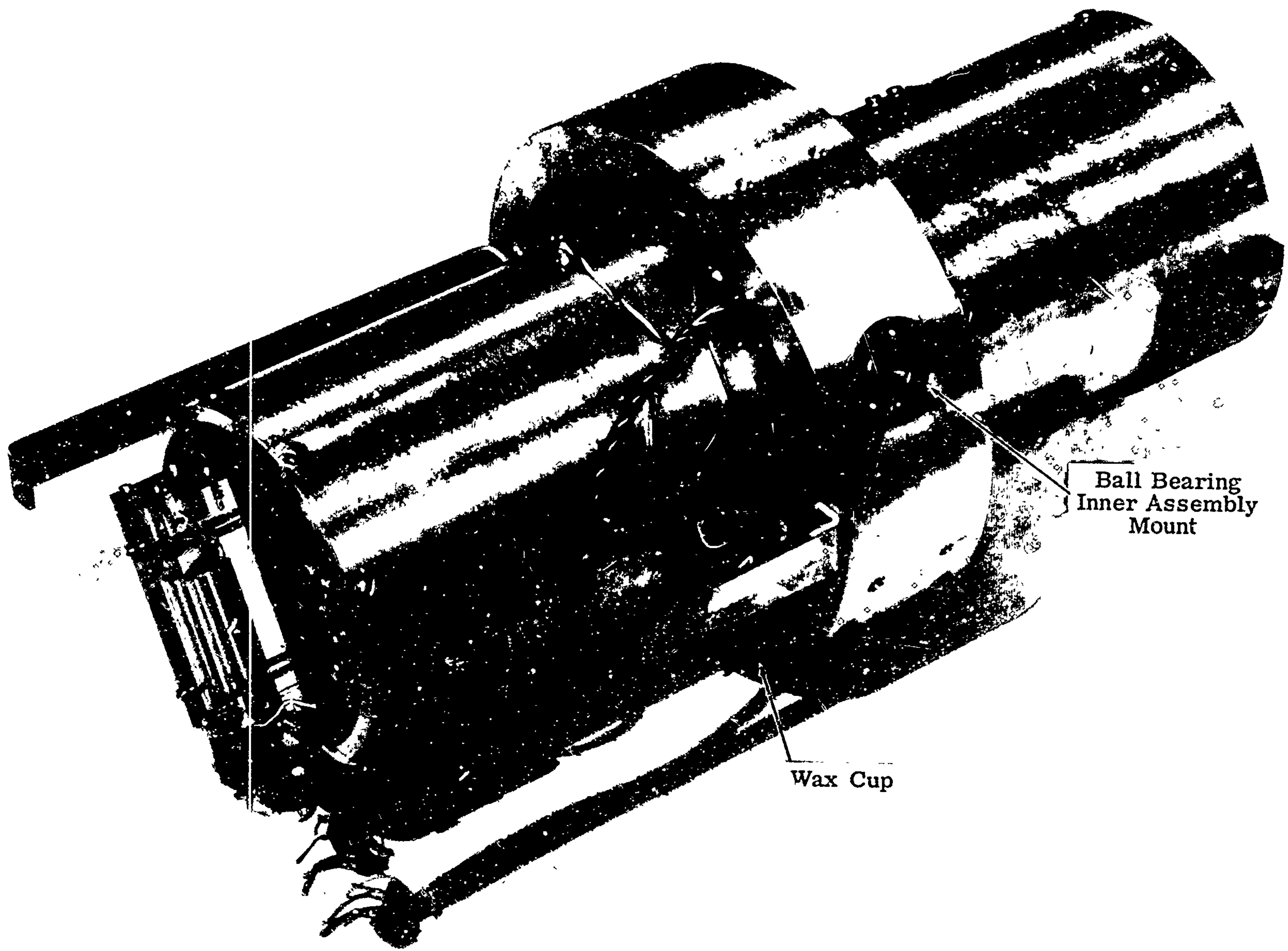

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Figure 22. Inner Cylinder of Horizontal Seismometer.

is filled with a wax which, when at ambient temperatures, is quite firm and easily capable of transmitting the designed 1 percent of the total inertial loading on the inner cylinder. There is sufficient imabalance provided in the inner cylinder assembly that, when the wax in the pot is molten, the inner cylinder will level itself to within 4 minutes of angle.

Since the instrument is essentially unaffected by transverse position, no provision is made for self leveling in this direction. There is, however, incorporated a position indicating switch which indicates remotely via warning lights on the control box, Figure 21, when the deviation from horizontal exceeds ± 30 minutes of angle in the longitudinal direction and ± 2 degrees of angle in the transverse direction. The warning light arrangement also indicates which direction from horizontal the instrument is tilted if the limits are exceeded. The warning light system was designed to be used only during installation of the instrument at the test station and, therefore, the control box with indicator lamps, was situated at the end of a 25-foot length of waterproof armored cable connected to the seismometer. Obviously, this is of no value during the actual test. Located at the control box also, is the switch to activate the heater, a shorting plug receptacle to release the mass, and cable connectors for battery power and for data output.

The seismic mass must be locked in its central position in order for the instrument to level itself. Provision is made for remotely releasing the mass (at the control box) after the wax has been melted, the instrument leveled, and the wax frozen again.

The seismometer proper, shown in Figure 23, is comprised of an inertial mass supported by ball bearings on two parallel steel rods which extend to the full length of the inner cylinder assembly (about 13 inches). Attached to the seismic mass are two ball bearing cam followers which are spring loaded in such a manner that they are pulled toward one another. These cam followers track on the opposite sides of a biconical cam extending the full length of the inner

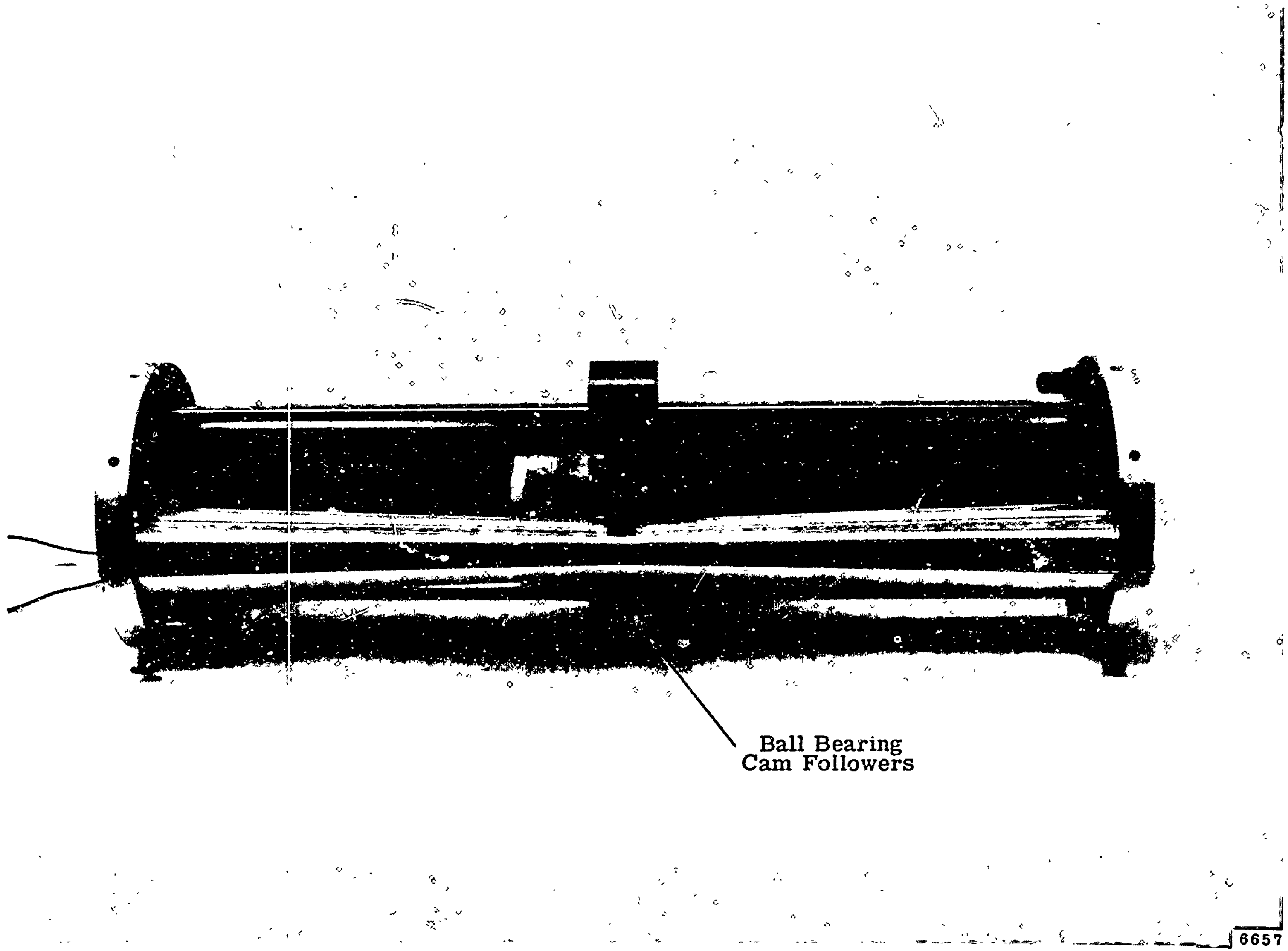

Figure 23. Horizontal Seismometer Inertial Mass Instrumentation.

Cylinder. This spring and cam arrangement provides the restoring force to return the mass to the center position after it has been displaced by the shock phenomena being investigated. This device provides a small spring deflection for a large mass deflection (a ratio of 12). The cam follower arms have a dashpot mounted between them which is filled with 400 cs silicone oil. The dashpot assembly is adjusted to provide 69 percent of critical damping to the seismic mass.

Also attached to the seismic mass are four electrical wiper contacts which traverse a deposited carbon resistance element and a gold plated copper strip. Both the resistance element and the metal strip extend approximately the length of the inner cylinder assembly. Electrical connections are made to each end of the carbon strip and to the metal strip. This arrangement forms a potentiometer which can be used as a voltage divider or as one or two arms of a bridge. The carbon resistance element was manufactured by the United Electrodynamics Corporation for this instrument and has a total resistance of about 1700 ohms. It was the sponsor's expressed desire that the seismometer be compatible with the Consolidated Electro-dynamics Corporation System "D" carrier-bridge amplifier system for field operations. In order to match this instrument to the System "D", it was necessary to build a matching box, shown schematically in Figure 24. This device also adds the capability of remotely "zero" balancing the electrical output of the instrument and of generating calibration steps equivalent to plus or minus 2-inch displacements for calibration purposes.

The original plans for field testing this instrument called for its installation in a horizontal bore 10 to 15 feet in length, drilled in the side of an underground tunnel. To meet this requirement, an insertion tool was designed and fabricated with which one can place the instrument in bores up to 20 feet deep and remotely detach it from the case.

Laboratory tests of the instrument under simulated shock environments were marginally successful. The limitation imposed by the laboratory setup was that the required energy to accelerate the 40-pound mass of the instrument to rates

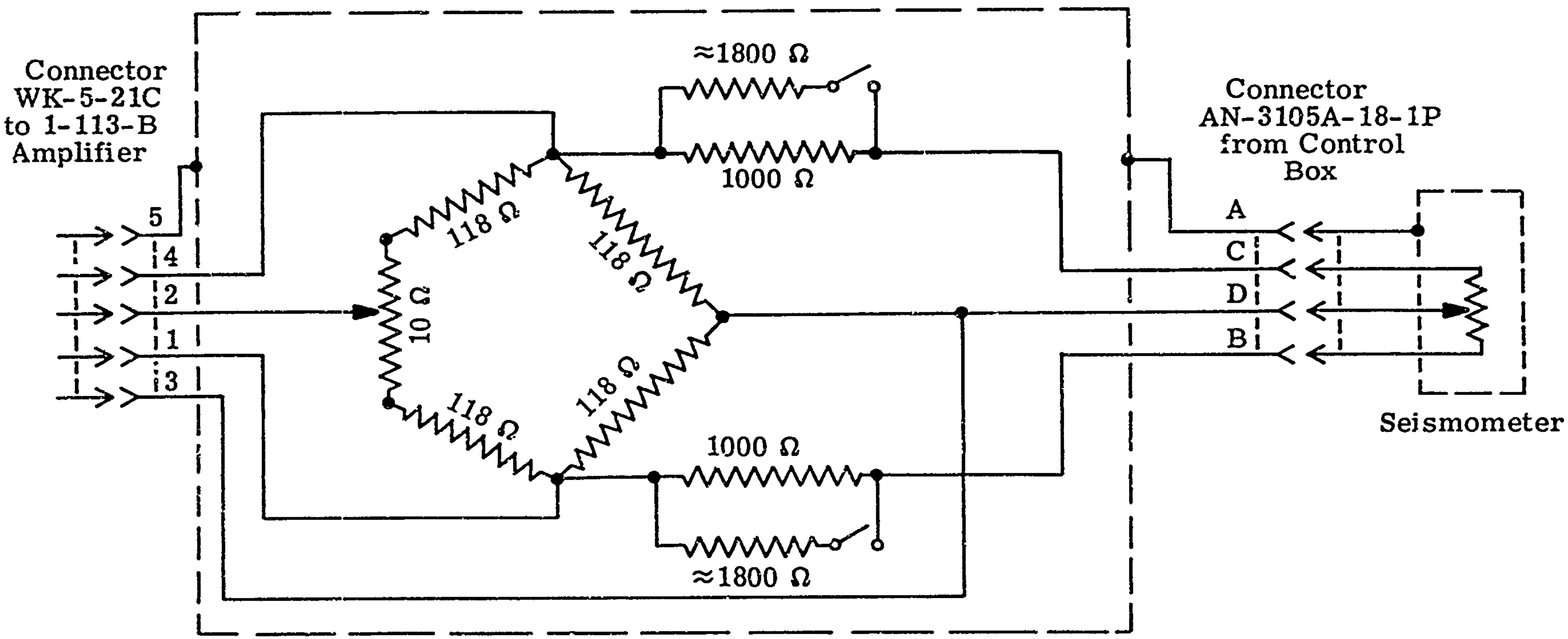

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Figure 24. Matching Box for Six-Inch Horizontal Displacement Meter to CEC System "D" Amplifier Type 1-113-B.

much higher than those associated with its natural period was not readily available.

Laboratory tests on the improvised shake table indicated that the instrument would faithfully transduce horizontal displacements up to 6 inches if the period of the impressed motion was one second or less.

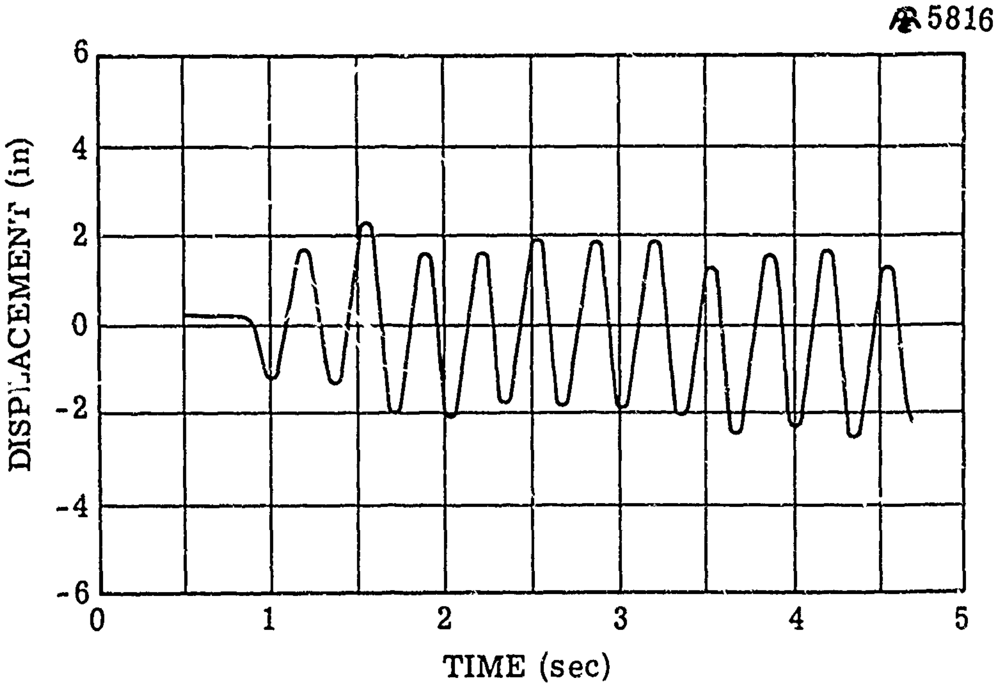
Tests using an approximately sinusoidal displacement input at a frequency slightly above the natural frequency of the instrument shown in Figure 25, indicate good fidelity of response.

Results of tests of natural period and damping ratio are shown in Figure 26.

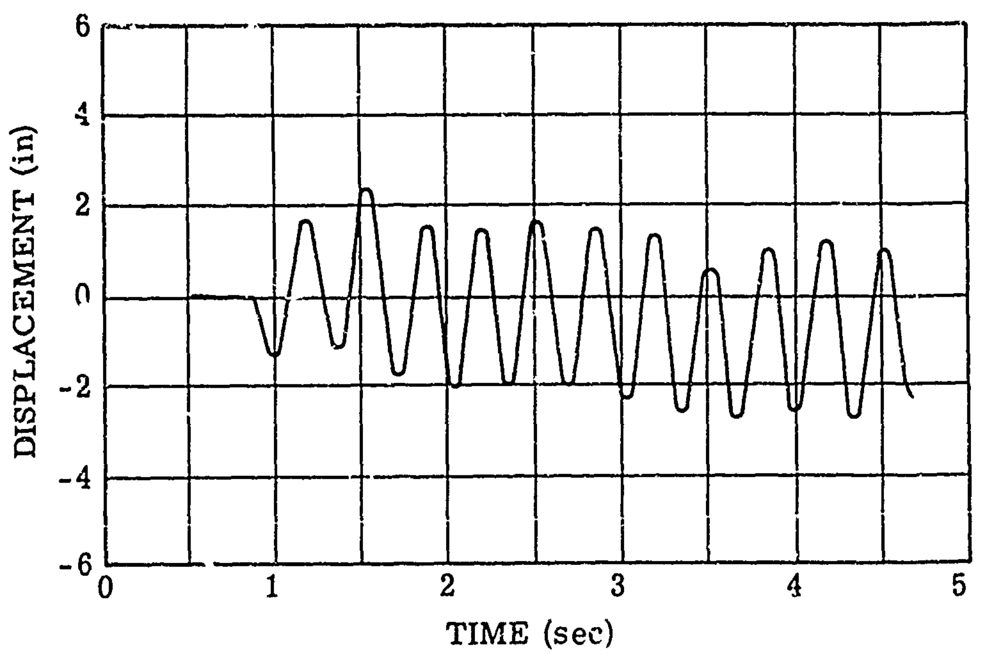
5.2 Field Test

On July 1, 1964, the instrument was taken to the Suffield Experimental Station, Alberta, Canada, by Mr. Willis Jackson of BRL to record the ground motions caused by the detonation of 500 tons of H.E. The location assigned for this instrument was 200 feet from the center of the charge. This would place it just outside of the anticipated crater. See Figure 27.

Unfortunately, no other supporting instrumentation was placed at this location. The instrument was buried 5 feet deep at the designated station, leveled, checked out and calibrated. The entire channel was then turned over to the field crew to check periodically until the time of the shot and to make it the final recording of the blast. Subsequent checks of the calibration prior to the shot indicated decreasing sensitivity for reasons unknown. Troubleshooting techniques were suggested by phone, but the results of these tests are not known. As a result, the calibration is meaningless, and tests since recovery of the instrument indicate that the resistance of the carbon trip may have been affected by the passage of excessive current during diagnostic tests. The absolute magnitude of displacements therefore could not be determined in this test.



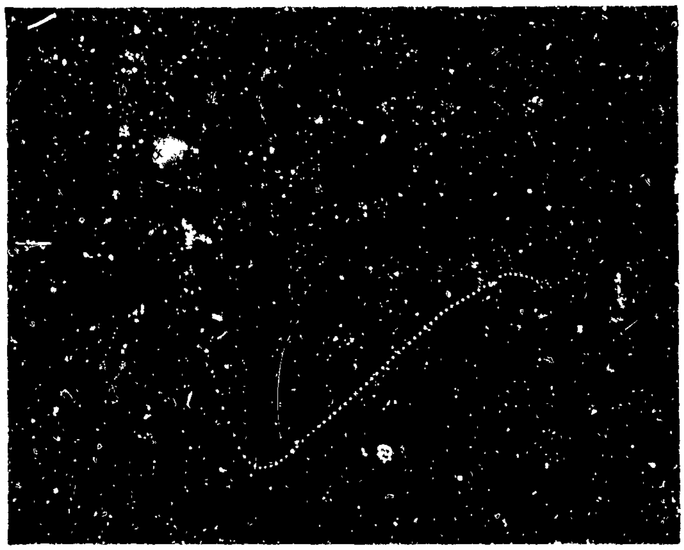
Seismometer Output (voltage)



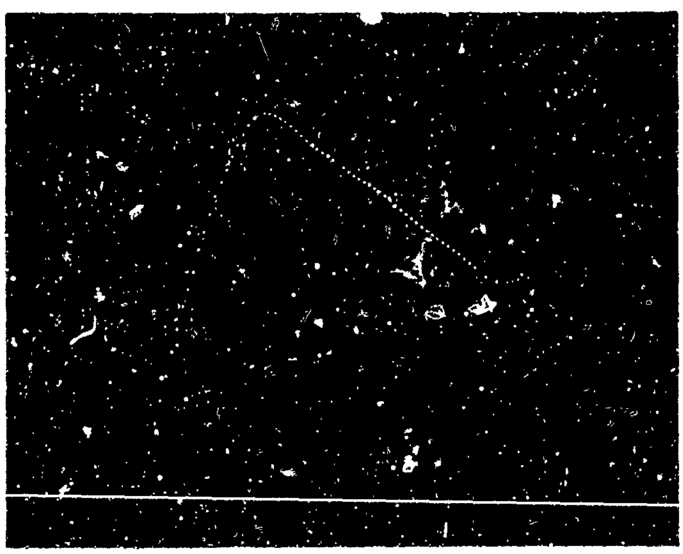
Seismometer Input (mechanical)

Figure 25. Fidelity Response of Horizontal Seismometer.

Timing Marks ≅ 100 msec (X Axis)
Y Axis 4 cm ≅ 6 Inch Displacement
Ratio of Successive Amplitudes ≅ 20:1
Per Cent Critical Damping ≅ 69



P = 1.5 Sec.



P = 1.5 Sec.

Figure 26. Natural Period and Damping Ratio.

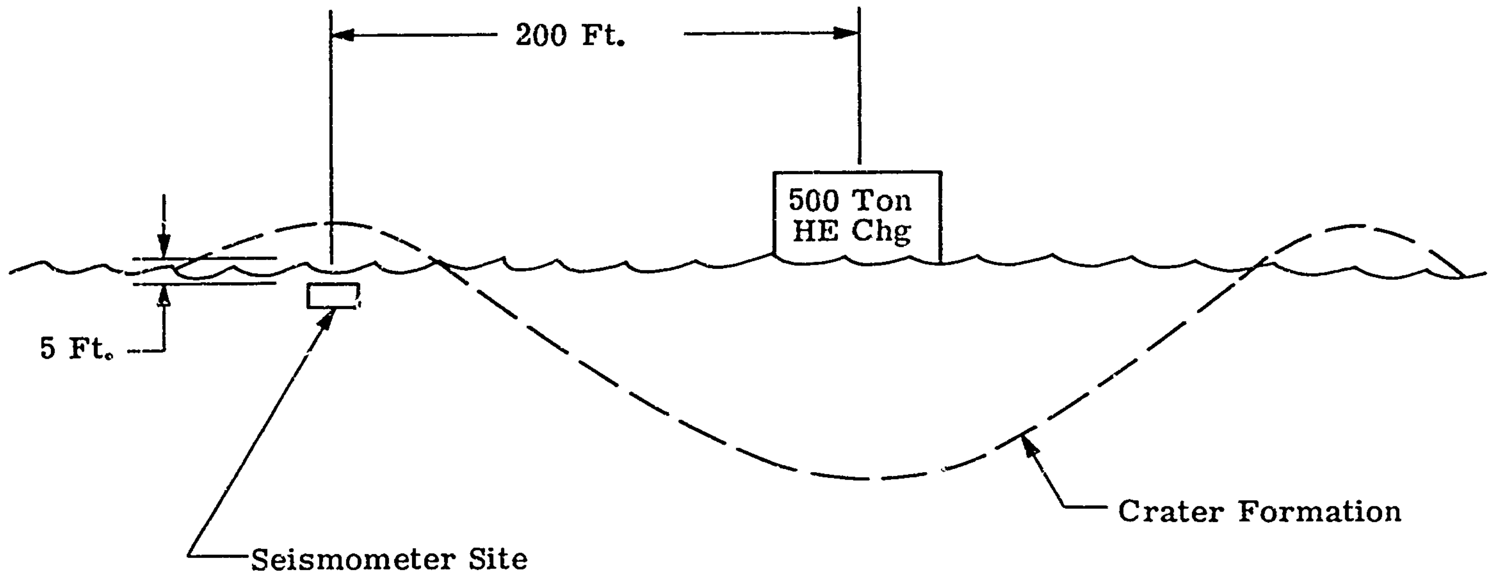


Figure 27. General Orientation of Test Station at Suffield Experimental Station.

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5.3 Evaluation

Analysis of this record indicates that the airblast-induced displacement arrived at the instrument at T = 0.024 second after the shot. The noise following the airblast wave is probably due to electrical causes. The surface layer and the instrument were probably set in vibration by the airblast. At 0.157 second, the initial displacement due to the arrival of the compressional "P" wave is shown. At 0.298 second, the arrival of a flexural wave is indicated. It appears that the combined effect of the "P" wave and the flexural wave were sufficient to exceed the limit of the instrument and the seismic mass came in contact with the arresting device after being displaced +6 inches. If one extrapolates the curve, it would appear that the total displacement was in the order of eight inches. At approximately 0.440 second, a negative displacement begins which is probably accompanied by some tilt as the instrument went off scale on the recorder at approximately 0.698 second and remained off scale until about 3.65 seconds, at which time it shows a positive displacement of about one inch. This event observed at 3+ seconds is believed to be a separate event due possibly to reflection from an impedance discontinuity located at the 5 to 10 thousand foot depth or possibly due to fallback of soil in the crater lip formation.

The velocity of the several waves is uncertain, since there is only one observation point and since the origin is broad compared to the distance to the observation point.

When the instrument was recovered and returned for post test inspection, damage apparently due to several causes, was observed. The suspension wire for the tilt indicating pendulum was broken. This is believed to be the only damage due to the blast. Other damage to the cable and connectors is believed to have been done in recovering the instrument from the test site.

Energy from the detonation can be transmitted to the instrument through several paths:

a. An airblast wave will propagate over the surface,

generating a seismic wave which will cause ground displacement at the instrument test station;

b. Compressional "P" waves and transverse "S" waves will be transmitted through each of the near surface layers (see Figure 28 for approximate geologic formation);

c. A Rayleigh wave will be transmitted through the top two or three layers and;

d. A flexural wave will very probably be transmitted through the surface layer.

In addition, as the crater is formed, the surface layer will be displaced away from the explosion as the soil is pushed out of the crater to form the lip.

These events will probably overlap on a time scale close to the explosion. Farther out, since the velocity varies for the different types of waves, there will be a greater time separation for the different events.

The horizontal seismometer is designed to be insensitive to transverse displacements, but should record the horizontal component of the various waves. The instrument will also respond to tilt of its longitudinal axis. It is therefore difficult in the present instrument to separate those phenomena due to tilt and those due to displacement except by assuming that response to tilt alone will be at the natural frequency of the instrument. Displacements faster than the natural response time of the instrument must therefore be forced displacements, but may be accompanied by some tilt.

A synopsis of the recorded data taken from this instrument during the Suffield Experimental Station shot in July 1964 is shown in Figure 29.

5.4 Recommendations

Recommendations for further development of this instrument are:

a. A new transducing element should be used which is less subject to degradation by currents used in ordinary test equipment and which is not so sensitive to contamination.

b. A level indicating device should be incorporated which

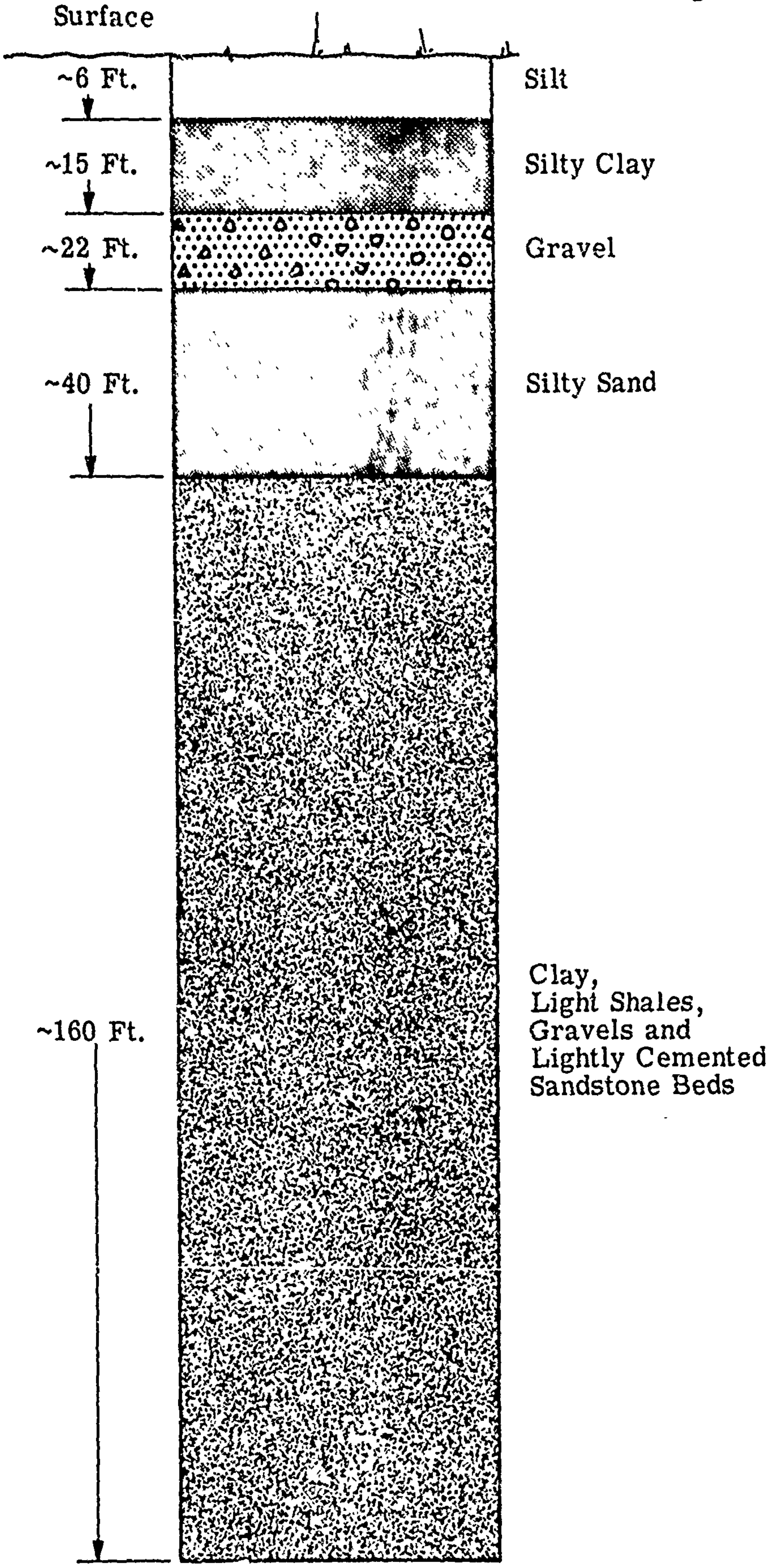

Figure 28. Approximate Thickness of the Various Beds to be Expected Between the Instrument Location and Impact Zone.

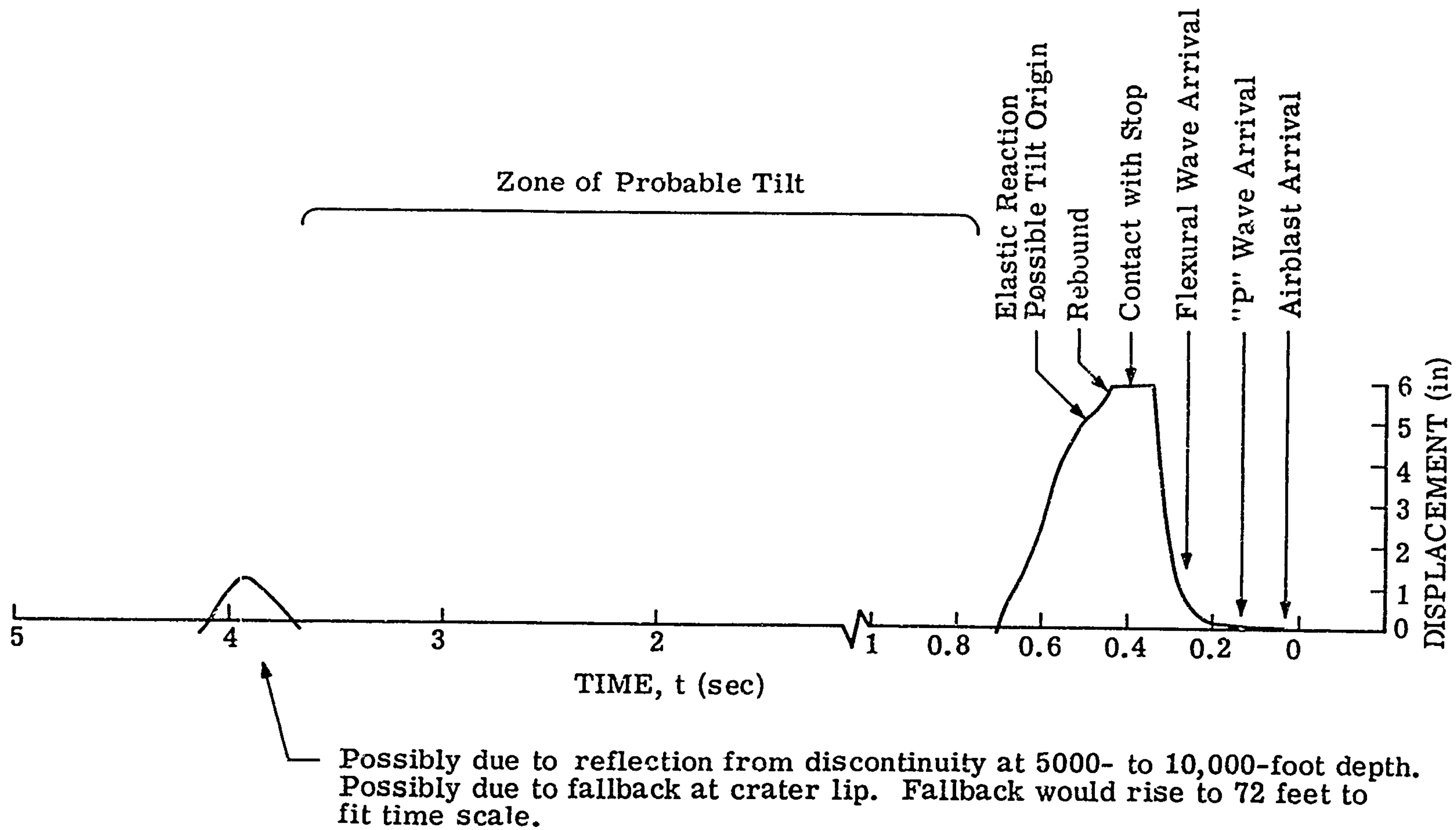

Figure 29. Synopsis of Recorded Data.

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will provide for continuous recording of the angle of the instrument both in the longitudinal and transverse directions while the displacement measurements are being taken.

c. For measurements in soil a more flexible cable can be used, thereby reducing the chances of the cable influencing the performance of the instrument.

d. A transducing element which does not contribute friction to the seismic mass will make possible a longer time constant for the instrument.

Future field tests of this instrument should have supporting instrumentation at the same station in order to fully evaluate its performance. Some possibilities in supporting instrumentation would be both horizontal and vertical velocity meters, photographic coverage of the test site with a Fastex camera and vertical posts to show gross shifts in the soil.

A contained explosion will provide a simpler phenomenon to observe since both airblast and crater formation will be avoided but displacement will be present.

6.0 DYNAMIC TRIAXIAL APPARATUS

In addition to the dynamic oedometer, the Ballistic Research Laboratories felt that another laboratory device for the measurement of Poisson's ratio should be designed and fabricated. Therefore a dynamic triaxial apparatus was designed by Atlantic Research Corporation under the direction of Dr. Werner Heierli and Dr. Alva Matthews of the Paul Weidlinger Consulting Engineering firm. A cross section of the laboratory device is shown in Figure 30.

The unit is somewhat similar to the conventional triaxial apparatus. However, it is designed for a maximum confining pressure of 1000 psi and has provisions for a rapid moving loading piston.

The unique feature of the proposed design was to determine Poisson's ratio by measuring the overall expansion of the soil specimen[(1)]. This could be accomplished only if the specimen deformed uniformly over the entire length. In conventional triaxial testing, nonuniform deformation can be attributed to the complex stress condition existing at both ends of the specimen. It was felt that this condition existed because of the friction imposed on the soil specimen by the confining end plates; hence, if this friction could be reduced to a negligible amount, it seemed possible that uniform deformation of the specimen could be obtained.

Two techniques were going to be tried in an attempt to reduce the end plate friction to a negligible amount. The first technique involved the use of the Teflon powder system that was tested in the earth shock tube. The surfaces of both end plates coming in contact with the specimen would be highly polished and a thin layer of Teflon powder would be placed between the polished surface and the specimen. The second technique would use the method developed by Dr. Rowe, University of Manchester, England. A thin flexible membrane is placed over the ends of the specimen coming into contact with the end plates. Between the membrane and the end plates a thin lubricating film of silicone oil is placed thus reducing the friction in this area to a minimum. In addition, the membrane is so flexible that it is easily stretched radially by

(1) Heierli, Weirner and Matthews, Alva T., Informal Report to Aberdeen Proving Ground, Paul Weidlinger, Consulting Engineer, Contract R6219 DA-30-069-AMC-8(R) May, 1963

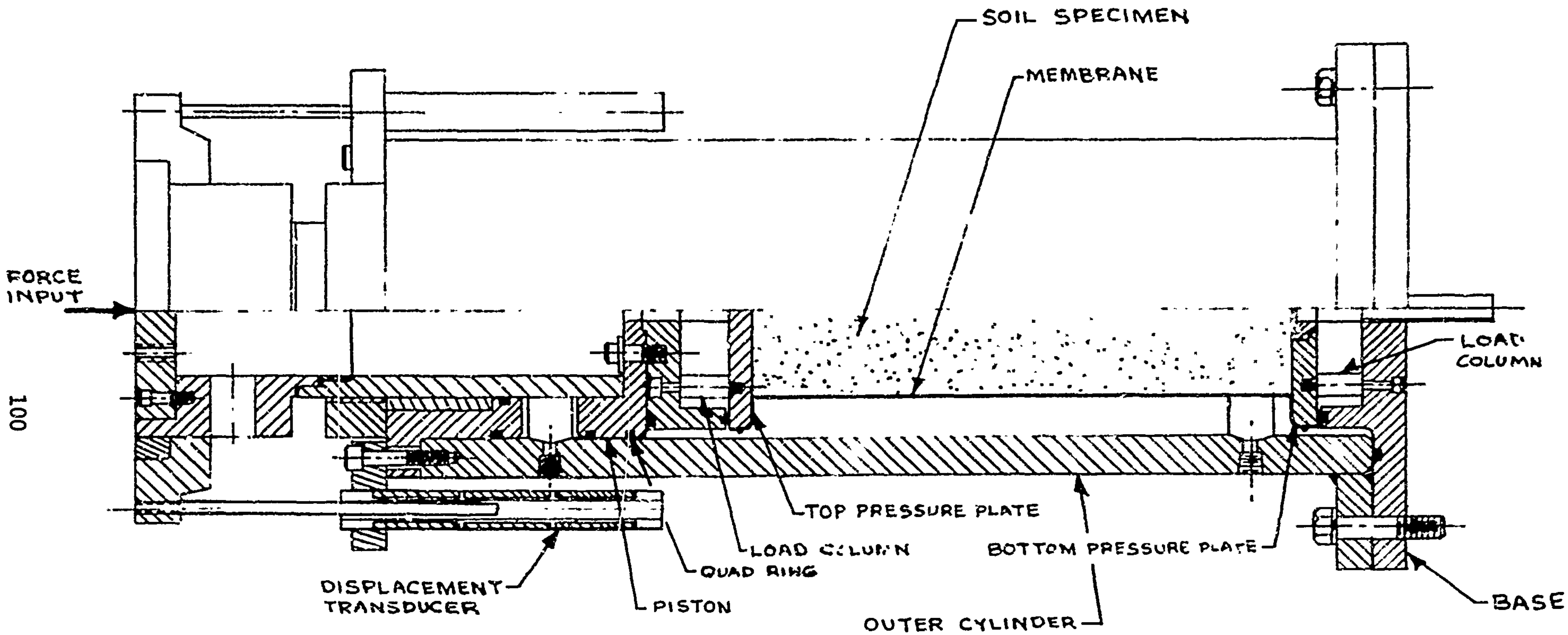
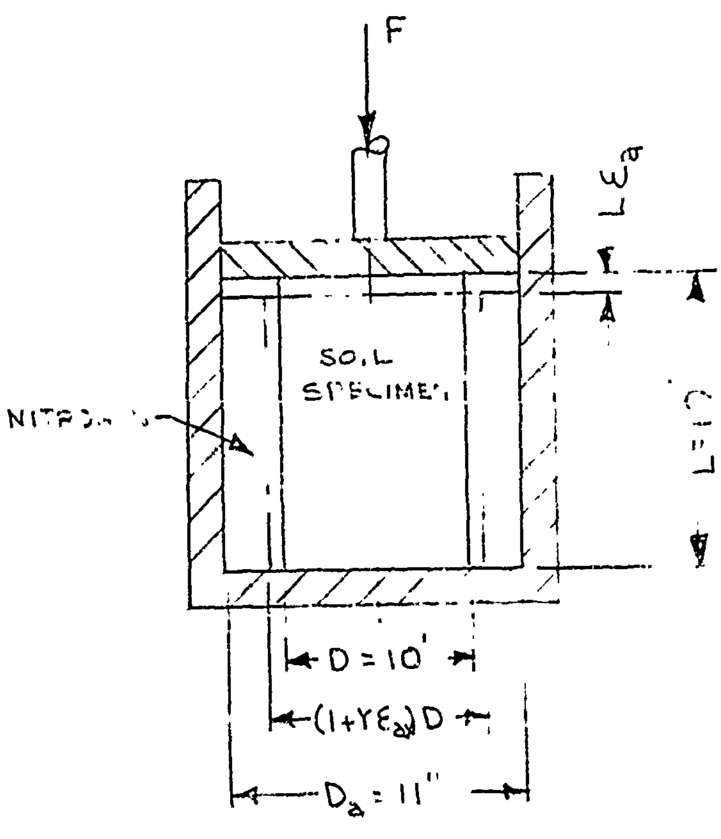


Figure 30. Dynamic Triaxial Apparatus.

the expanding specimen thus it acts as a part of the soil and does not add any appreciable strength to it. Therefore, it was felt that one of these two techniques would allow uniform specimen deformation, from which one could determine a representative value of Poisson's ratio of the specimen.

If the friction at the end plates could be overcome and a uniform deformation of the specimen could be realized, a method had to be devised to measure the lateral expansion of the soil. When the top plate moves downward, the sample expands in cross section and the volume of gas contained in the cavity surrounding the specimen decreases. Thus, the pressure increase in the gas can be attributed to both the downward motion of the piston and the radial expansion of the soil specimen. Since the downward motion of the piston is measured by the Schaevitz LVDT gages, the pressure increase due to this motion could be readily calculated and deducted from the total pressure increase to yield that pressure increase directly attributable to the radial expansion of the soil specimen. An example as worked out by Dr. Heierli is shown below.



Soil

$E = 5000$ psi (Young's Modulus)

$\gamma = 1/3$

$\Delta\sigma_{ax} = 100$ psi (axial stress increment)

$\Delta\varepsilon_{ax} = \frac{100}{5000} = 0.02$

Nitrogen

Δp = Unknown (psi)

$p = 15$ psi (initial confining pressure

$V_o = 165\ in^3$ (initial volume of gas)

$\Delta V_a = (-165)(0.02) = -3.30\ in^3$ (change of volume of gas due to motion of plunger)

ΔV_e = Change of volume of gas due to soil expansion

Now

$$\Delta V_e = -\left[\frac{\pi(1 + \gamma\varepsilon_a)^2 D^2}{4} - \frac{\pi D^2}{4}\right]\left[L - L(\varepsilon_a)\right]$$

$$\Delta V_e \cong -\left(\frac{\pi D^2 L}{4}\right)(2\gamma\varepsilon_a)(1 - \varepsilon_a)$$

Substituting, we have

$$\Delta V_e \cong -10.25\ in^3$$

The volume of gas decreases by $\Delta V_z + \Delta V_c = 16.80\ in^3$, of which $10.25\ in^3$ are due to the expansion of the soil. The corresponding pressure increase in gas pressure Δp is, with $\chi = c_p/c_v = 1.40$ (the ratio of the specific heats at constant pressure and constant volume, respectively):

$$\Delta p - (-p)(k) \cdot \frac{\Delta V}{V}$$

(from $p \cdot V^k$ = (const. for adiabatic compression)

$$\Delta p = (-15)(1.4)\left(\frac{-10.25 - 3.30}{165}\right) = 1.73 \text{ psi}$$

The pressure increase can be measured with a precision differential pressure transducer. The pressure increase can be calibrated in terms of volume decrease of the gas in dynamic tests.

One problem area using this approach must be investigated; that is, the increase in gas pressure adds to the initial confining pressure. Therefore, the gas pressure increase must be small enough not to influence the test, but it must be large enough to be measured with relative ease. An attempt was made to assure that this situation would exist, but as yet it has not been proven.

6.1 Design

6.1.1 General

Several designs of the dynamic oedometer were incorporated into the dynamic triaxial apparatus; namely, the pressure plate design and the use of strain gage columns to measure applied and transferred loads. It was intended to use the "Hyge" pneumatic device described in paragraphs 3.2 and 3.3, as the force applicator.

The triaxial apparatus consists of three main members, the outer cylinder, and the top and bottom pressure plates. The soil specimen was to be prepared in a 4 inch diameter flexible membrane which was confined by the top and bottom pressure plates. A pressure pulse was to be introduced into the specimen through the guided top pressure plate. The displacement of this plate was to be measured by two diametrically opposed Schaevitz LVDT gages. The input pulse was to be measured both by the load column arrangement and a Baldwin-Lima-Hamilton Load cell placed between the applicator and the top pressure plate assembly. As the pressure pulse passed through the specimen it would be measured by the load columns in the bottom pressure plate assembly which is identical to the top plate assembly.

The movement of the top pressure plate is guided by a piston assembly placed in an oilite bushing. The piston itself has a double sealing arrangement which should keep leakage down to an extreme minimum. Since the piston moves quite rapidly, it was felt that Quad sealing rings should be used to prevent twisting of the rings.

6.1.2 Pressure Plates

The average pressure at the top and bottom of the soil specimen is measured by identical arrangements of a pressure plate supported by four equally spaced load columns. The plates which form a part of the pressure plate assembly are designed to be as light as possible to minimize inertia effects, and still be strong enough to exhibit sufficiently small deflections. The mass above the load columns does not influence the inertial pressure loss of the plate.

When tests of gages imbedded in the soil specimen are desired, a terminal arrangement consisting of a Teflon plug and wire pins is inserted into the bottom pressure plate to facilitate the electrical connections. To minimize interference between the movement of the soil particles and the Teflon plug, the plug is centrally located and mounted flush to the pressure plate surface.

6.1.3 Load Columns

The average pressure at the top and bottom of the soil specimen is measured by load columns. These load columns are to be instrumented with standard resistive foil elements connected in a Wheatstone bridge arrangement. Piezoresistive strain elements were considered to instrument the columns because of their high gage factor; however, it was decided that their high temperature coefficients would produce many drift problems.

Foreign matter is kept out of the load column cavity by sealing off the volume with "O" rings. The "O" ring in contact with the pressure plate has minimum squeeze on it, so that it would not influence the pressure plate loading.

6.1.4 Cylinder

The outer steel cylinder was designed for 1000 psi internal pressure, with a substantial safety factor. Therefore, at all confining pressures, the lateral deformation of the outer cylinder will be negligible. Thus, the increase of gas pressure will be due entirely to the downward motion of the piston and the deformation of the soil specimen.

The inner surface of the cylinder is highly polished in order that a minimum amount of friction would be realized from the movement of the quad sealing rings.

6.1.5 Force Applicator

Pressure input into the triaxial apparatus was to be accomplished by a pneumatic loading device, the "Hyge" unit which was used on the earth shock tube. The assembly was to be mounted vertically on a concrete foundation with the "Hyge" unit anchored on a suitable frame assembly and the driving ram attached directly to the top of the triaxial piston assembly.

6.2 Testing

Because of limited funding, the dynamic triaxial apparatus was never assembled; therefore, no testing could be done.

7.0 SUMMARY

In the course of the contract, effort was expended in several areas including

1. strain gage development
2. earth shock tube experimentation
3. development of laboratory equipment
4. development of a horizontal displacement meter

The contract funding was such that only a low level of effort could be expended by Atlantic Research Corporation.

As problems occurred in one area, effort was normally transferred to other areas of interest before solutions to the problems could be found.

The results of the program may be tabulated as follows:

Earth Strain Gage

After modifications to original design, satisfactory results were obtained from these gages in some of the tests run in the earth shock tube.

Earth Shock Tube

This equipment was designed and installed, and five series of tests were performed during the contract. An evaluation of the Teflon powder friction reduction system was not completed. In general, the use of the shock tube for evaluation of gages was not successful because of the anomalously high gage output which was recorded.

Dynamic Oedometer

The unit was designed and instrumented under this contract, but tests and evaluations were conducted under a subsequent contract and are reported in Part II of this report.

Dynamic Triaxial Apparatus

The triaxial apparatus was designed and fabricated but funding was never allocated for assembly of the system.

Horizontal Displacement Meter

This seismometer was designed and field tested. The test results were evaluated and recommendations were made for improvements but no further work was carried out on this unit.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Due to limited funds some of the studies were stopped before conclusive data were obtained. These investigations are noted below and the indications of the limited study are given.

a. Earth Shock Tube

The tests conducted with the earth shock tube showed that soil samples confined in tubes having large length to diameter ratios cannot be used for one dimensional wave propagation studies. This confirms the conclusions of others[1]. However, observations from the earth shock tube tests indicated that uniform density throughout the length of the sand sample was not achieved, and the Teflon powder layer between the sand and the confining tube was not sufficiently compacted. The tests conducted with the Teflon powder friction reduction system are inconclusive because of anomalous pressure measurements of the wave propagating through the soil sample. In an attempt to evaluate the behavior of gages embedded in the earth shock tube, it was found that the costs were excessive. Therefore it was decided that the gage behavior should be studied in the laboratory with the aid of laboratory devices such as the dynamic triaxial apparatus.

b. Earth Strain Gage

During the limited testing of the earth strain gage, it apparently operated satisfactorily. However, because of the anomalous pressure measurements, no meaning could be attached to the values obtained with this device. Because of its simplicity and low cost, it is strongly recommended that further testing should be done with this gage. Its precision should be verified.

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(1) R.V. Whitman, et al, "The Behavior of Soil Under Dynamic Loadings," Volume 3, Final Report on laboratory studies; Massachusetts Institute of Technology; Contract Number DA-49-129-Eng-227, August 1954.

c. Dynamic Oedometer

The conclusions and recommendations for this phase of the project have been given in Part II of this report. As stated previously, it is highly recommended that effort be devoted to further evaluation of the dynamic oedometer.

d. Horizontal Displacement Meter

The conclusions and recommendations for this phase of the project have been given in Part I, Section 5.0 of this report.

e. Dynamic Triaxial Apparatus

The components of this device were fabricated, but due to lack of funds it was never assembled. Therefore, no conclusions could be drawn. However, the following recommendations are made:

1) that the device be assembled and that initial work be directed to the study of the behavior of imbedded gages;
2) the results of the initial study should then be directed towards tests of the earth shock tube using the Teflon powder friction reduction system. The conclusions of these tests may evolve an economical laboratory device to be used for one dimensional wave propagation or yield information which will lead closer to the realization of such device.

PART II

DYNAMIC OEDOMETER

Contract DA-18-001-AMC-877(X)

1.0 INTRODUCTION

This section of the report is concerned only with the tests on soils performed under a later contract, DA 18-001-AMC-877(X), with the Ballistics Research Laboratories of the U.S. Army.

These tests made use of the dynamic oedometer and some other items which have been described in Part I of this report. The oedometer was designed to investigate soil compaction and imbedded stress gage behavior before further earth shock tube tests were carried out (Part I of this report). In addition to the investigation of stress gage behavior under conditions of one-dimensional stress, it was hoped that experiments could be conducted to determine accurate values of constrained modulus, Poisson's ratio, and other soil constants useful for propagation predictions. The test series was intended to measure, for certain chosen soils, the calibration factors for buried gages and values for dynamic behavior parameters in support of planned tests in the earth shock tube. However, the sets of measured data and other observations during the tests indicated unexpected results, specifically that the loading piston developed a tilt during tests, and that a uniform state of stress could not be easily achieved if lateral displacement of the sample was not permitted.

This report describes these tests and discusses some alternate mechanisms which may possibly have combined to cause these apparent findings in the tests performed.

2.0 DESCRIPTION OF TESTS

2.1 Apparatus

The dynamic oedometer is a laboratory device to be used to investigate soil compaction and imbedded stress gage behavior. It was also expected that the device would be useful in one-dimensional wave propagation studies. Figure 1 is a sectional sketch of the oedometer, and Figure 2 is a photograph of it assembled for use within a frame provided for the support of the loading device. The loading device shown is an ordinary hydraulic ram for static tests. For dynamic tests, the oedometer equipped with the Hyge Shock Tester, Figure 3, is capable of developing a maximum loading

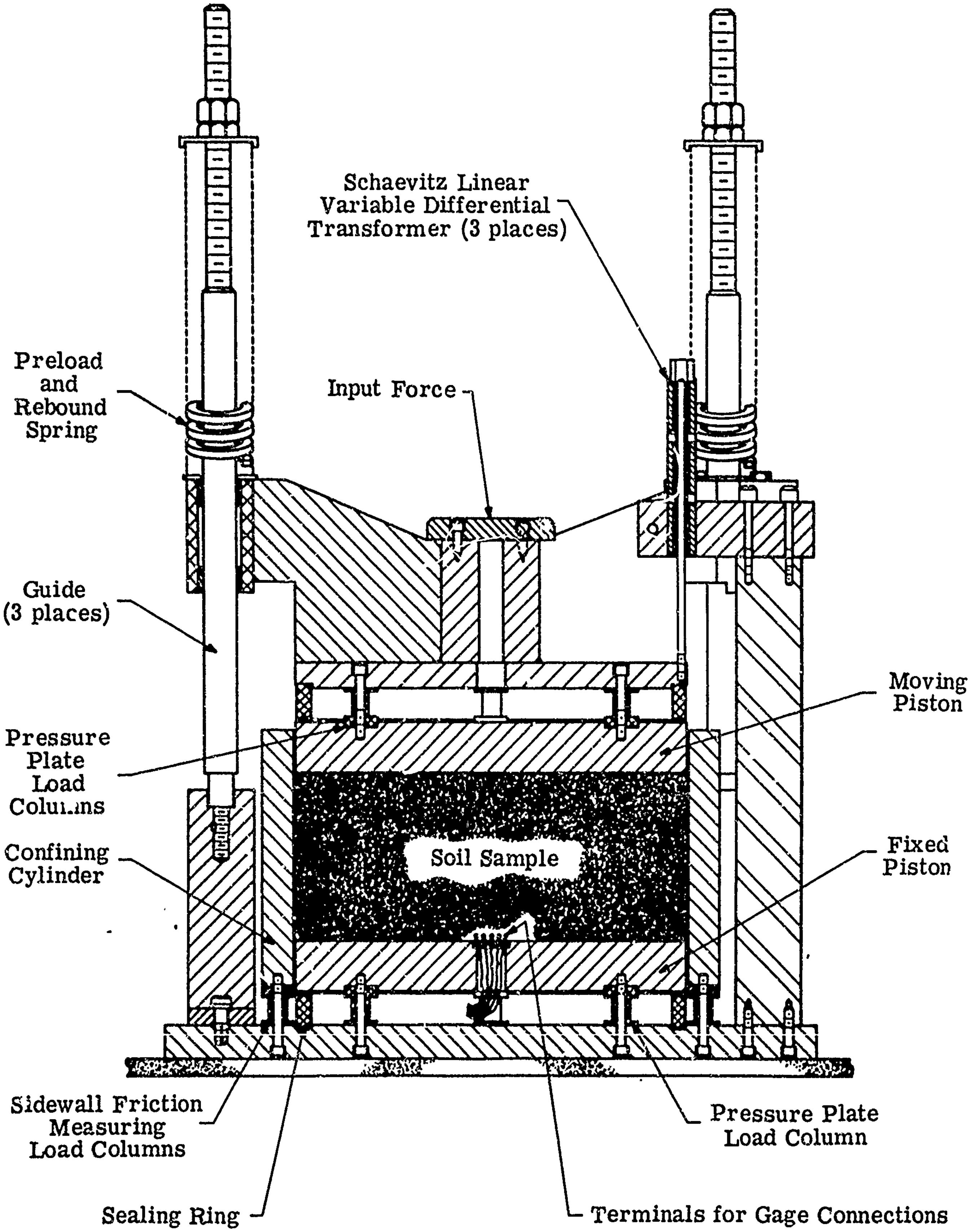

Figure 1. Cross Section of Dynamic Oedometer.

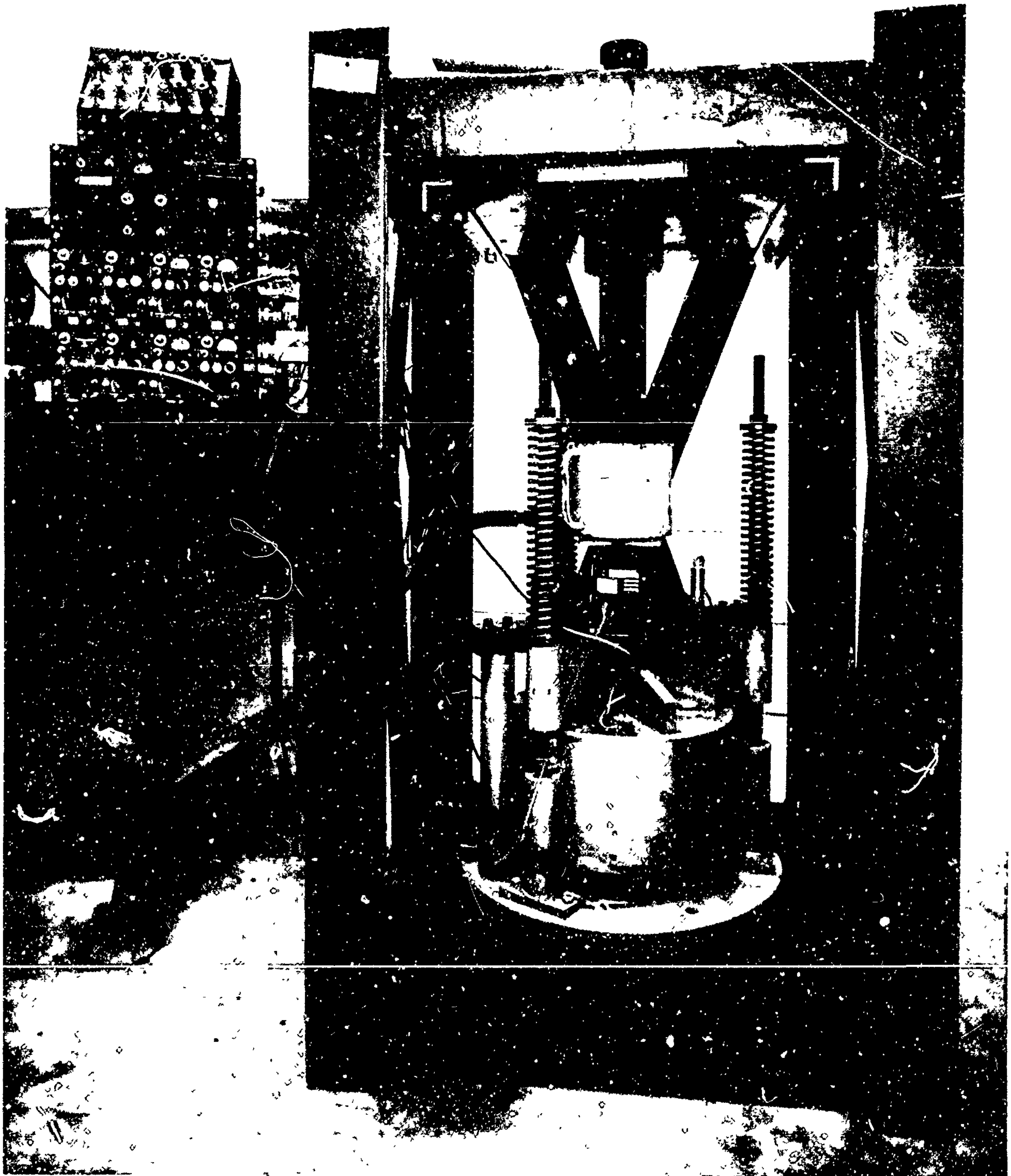

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Figure 2. Oedometer with Hydraulic Ram Installed for Static Test.

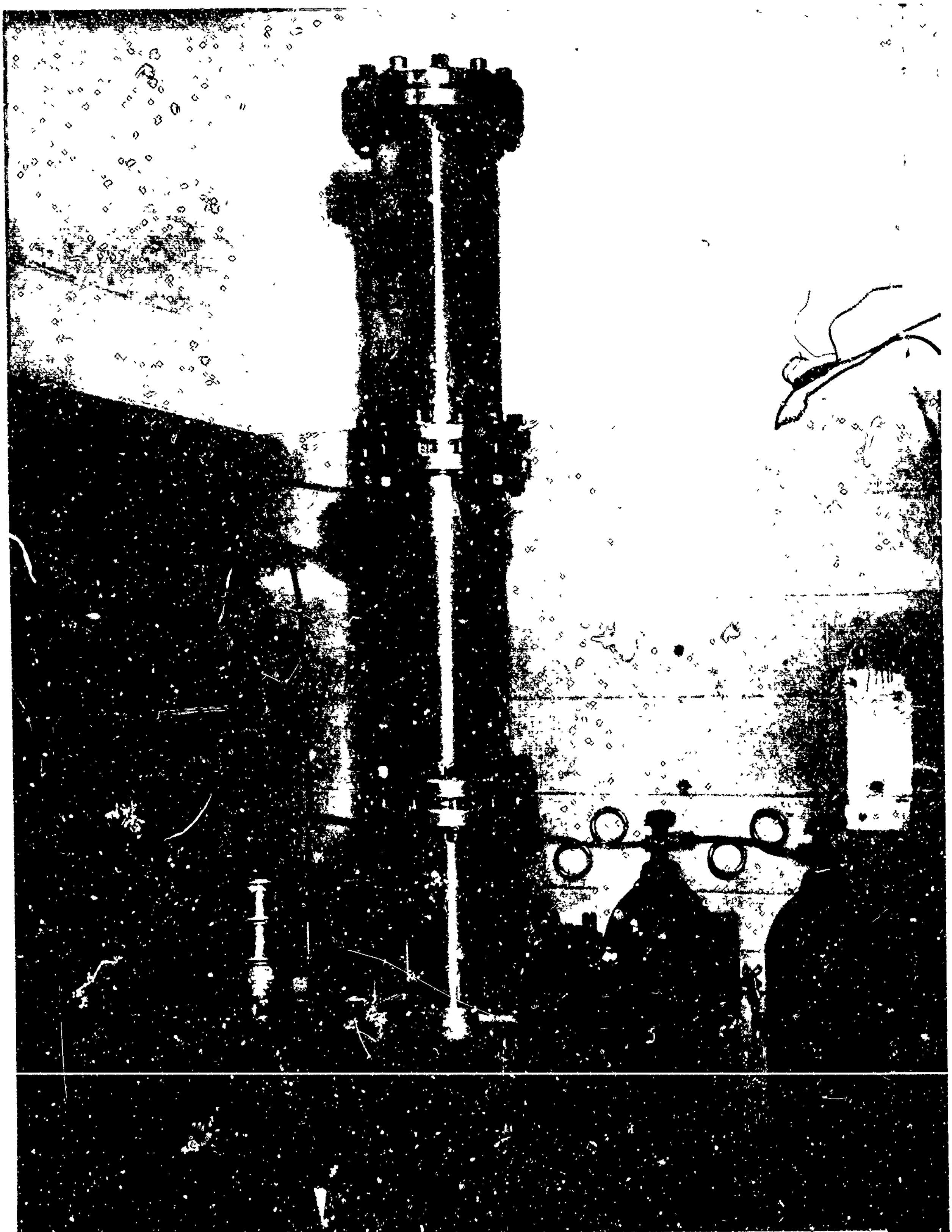

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Figure 3. Hyge Shock Tester Mounted on Oedometer.

of 40,000 pounds, with rise time of a few milliseconds when the motion of its piston is resisted by a test system of sufficient rigidity. It operates by the sudden delivery of high-pressure nitrogen gas to a cylinder and piston through a fast-acting valve. In static tests, to provide smooth and precise increases in force up to the peak value which was preselected for each test, several hydraulic rams were used of which the largest has a 60,000 pound rating. A 50,000 pound dynamic load had been used in the design of the oedometer, the loading frame, and other apparatus to which it might apply.

The details of the oedometer are given in Part I of this report and need not be repeated here. The oedometer has been designed to accept a cylindrical soil sample, nominally 12 inches in diameter and 6 inches high. It has a heavy steel base plate, to which a disc, serving as the bottom piston, and an outer wall, consisting of a machined heavy pipe section, are firmly attached by means of four spool-shaped forced links each. Also attached to the base plate are 3 heavy rods to guide the upper piston, and the supporting posts for gages to measure that piston's motion. The upper piston is a thick aluminum disc attached by four more force links into a heavy assembly of steel plates and discs to form a rigid unit. This unit distributes the concentrated loads delivered to its top and connects the piston with the bearings which slide freely up and down on the guide rods. To control rebound and to permit preloading a sample when desired, a compression spring extends up from each of the bearings to a nut and washer on the threaded upper end of each guide rod. Actually, the upper and lower pistons themselves are identical. Each is a 1 1/2 inch thick aluminum disc, fitted to a 0.010 inch clearance with the oedometer wall. This opening was designed to be small enough to prevent intrusion of Ottawa Sand of the size retained on a No. 30 ASTM wire mesh, but large enough to be maintained open by the rigidity of the guide rods.

Gages attached to the oedometer parts permitted the following measurements:

The set of force links assembled to the upper piston measured the force delivered by the loading device to the upper surface of the soil sample.

The links under the lower piston provided a measurement of the force delivered through the sample and piston to the base.

The difference between these two quantities was considered to have been transferred to the walls by friction, and was measured by the set of force links which support the wall.

Strain gages were applied to the wall to detect the strain in a circumferential direction at two distances from the base to measure circumferential tension in the oedometer wall. Obviously, this strain results from the force exerted by the soil in its tendency to spread laterally under a compressive vertical load. To minimize this motion and so relate the measurement to Poisson's ratio, the wall had been designed far thicker than required for the design loads but was provided with broad vertical notches for the installation of the strain gage. The remaining measurement made on the oedometer was of the motion of the upper piston relative to the base plate. Originally, the two linear-variable differential transformers, were mounted with their cores attached to the upper piston unit at opposite ends of a single diameter. During the test program, it was found necessary to increase the number of transformers to three, equally spaced around the edge of the head unit at a radius of 5 5/8 inches from its center.

2.2 Instrumentation and Calibration

Each of the four force links in each of the three sets was fitted with resistance strain gages. The bodies of these links were spool-shaped with a central hole for a mounting bolt. Because the four in each set connected two rigid elements, and because their cross section was held to a minimum to increase sensitivity, their installation and calibration presented a problem. In actual soil tests, all in

each set were to be electronically connected to provide a single output signal. With a set of four between two rigid plates, however, the output would not be linearly related to the load through the full range unless each in the set was equally preloaded. Otherwise, one or two might not start carrying load at the beginning of a cycle, while another might be above its yield stress when the load approached the design value for the set. Furthermore an adequate preload was needed to provide proper operation during rebound in dynamic tests. These problems were solved by connecting each force link to give a separate electronic output before assembly of each set to the mating parts. By monitoring of these outputs, the lengths of the separate links could be adjusted by shimming and light filing to give simultaneous contact under no load, and the mounting bolts tightened to adjust each to the chosen preload. After assembly in this manner, each set was checked and found to have an output curve of adequate linearity and precision under the proper range of calibrating loads.

The strain gages reading tension in the oedometer wall were of the semiconductor type. These offered better temperature compensation at the expected low stresses than strain gages of the metallic type on the 1/4 inch thickness of steel left under the vertical notches in the wall where the gages were to be applied. Better compensation was achieved by building bridges with pairs of elements oriented at right angles to each other, having a positive and negative gage factor, and aligning only the proper one of each pair in the direction of the strain to be measured. Naturally, the element at right angles made the pair also sensitive to strain at right angles to that desired to be measured, which in this case would be expected to result from soil friction. However, the strain from such vertical forces was negligible, in comparison, when estimated values for both forces were each divided by the appropriate cross-sectional area for the wall. Since the wall was 1 inch thick except at the notches, its horizontal cross section was nearly 60 times the area of the metal left at the notch. This conclusion was verified,

and the bridge calibrated, by subjecting the wall ring to several combinations of vertical load and internal air pressure. With the ring resting on a rubber sheet on the metal floor of the loading frame, the vertical load was imposed on its top by a hydraulic ram through a stack of steel plates and another rubber sheet. The vertical load was chosen to be more than needed to keep a seal between the ring and the rubber sheets and also to hold the plates down against the air pressure. Output of the ring tension bridge was monitored while the vertical load was imposed as well as while the air pressure increments were being added through a valve and gage system. The actual gages used were Kulite-Bytrex Corporation Types DB-102 and DBN-102.

Motion of the upper piston was measured by Schaevitz Engineering Model 1000 S-L linear variable differential transformers (LVDT). As mentioned, the number used was increased from two to three during the tests, after tilting of the upper piston had been observed. The cores for these gages are mounted vertically in threaded holes near the edge of the upper piston assembly, and the armatures were held in adjustable clamps supported by the oedometer base plate. The cores are adjusted to an appropriate zero position after the soil sample and the rest of the apparatus are in place.

In addition to the measurements of forces on, and motions of, the soil samples, provision was made for the operation of gages within the soil samples. Leads for such gages were connected through a fitting installed in the bottom piston. The number of internal gages varied from none in some tests to three in others. All gages used were Kulite-Bytrex Model HFA-1000 pressure cells. These were disc-shaped gages approximately 2 inches in diameter, having a rubber diaphragm which was stiffened by a thin metal disc and backed with oil which transmits pressure changes to the semiconductor-type transducer.

For both static and dynamic tests, data were recorded through the 3KC carrier amplifiers and other parts of a CEC System D conditioning unit, with other electronic elements as required, on a CEC Model 5-124 oscillograph. At most, 12 channels of data were recorded. Of these, mentioned above are the upper piston force, the lower piston force, the force delivered vertically by the sidewall, the tension in the sidewall, 3 channels of data on the upper piston motion, and as many as 3 records from the gages buried in the sample. In addition, in static tests a load cell was installed under the loading ram to check on the piston load cell outputs. This load cell was a Baldwin-Lima-Hamilton SR-4 Type C rated to 50,000 lb.

2.3 Auxiliary Equipment

Some auxiliary apparatus was needed to make the performance of soil tests possible with an oedometer of the size and type described. In addition to standard laboratory equipment for measurement and control of sample properties, the principal items were a jig for raising and lowering the movable piston, and a sleeve for placing a Teflon liner at the periphery of certain samples of soils. The jig shown installed in Figure 4, was designed to permit precise and deliberate handling of the assembly, and to eliminate shocks or other disturbances to the sample. With it, the oedometer can be in place in the loading frame during sample placement, removal, and all other parts of a test. The sample is thus provided with some isolation from environmental vibration and disturbance by the rigidity and weight of over a ton represented by the loading frame itself, as well as being protected from the obvious changes which would result from moving the assembled oedometer or man handling the loading piston. Figure 5 shows the sleeve for placing the Teflon liner which was simply a thin cylinder of sheet metal, which can be set in the oedometer and has a diameter 1/2 inch smaller. To provide a controlled sample with a thin lubricating layer of Teflon separating it from the oedometer wall, the sample is placed within the sleeve and the Teflon powder in the space between the sleeve and oedometer wall. The sleeve is

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Figure 4. Jig for Handling Movable Piston Installed on Oedometer.

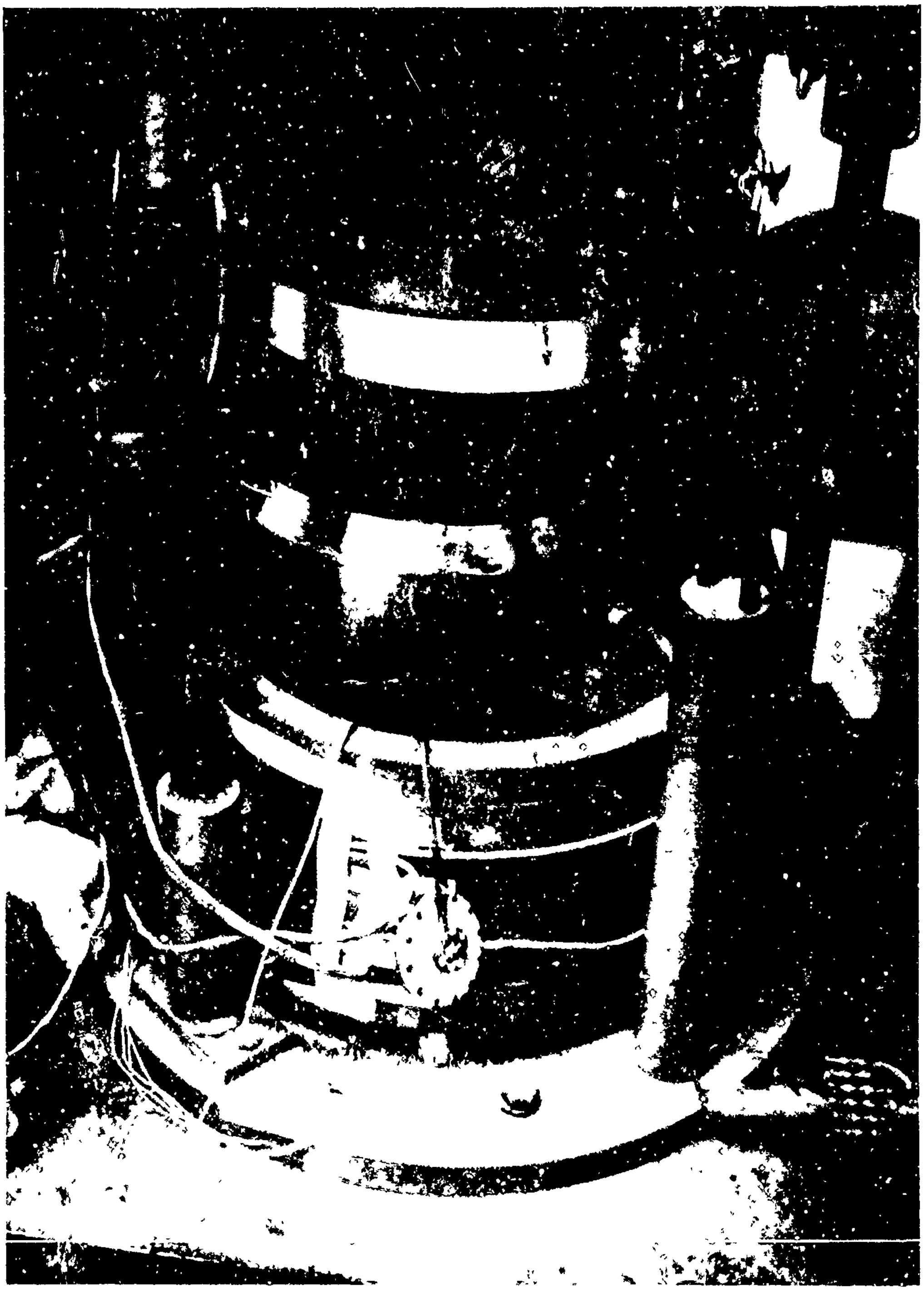

Figure 5. Sleeve for Placement of Teflon Powder Lubricant. 17404

withdrawn slowly as the height of the sample is increased. This caused a minimum disturbance of the sample and Teflon lubricant.

3.0 TEST PROGRAM

The actual program consisted of a series of static and dynamic tests on a set of soil samples providing some variety in their properties. The planning of such a program was aided by the fact that all gages and instrumentation were useable in both static and dynamic tests without change. However, the difficulty in changing the loading device from the static rams to the Hyge Shock Tester, and the demand for use of the latter on other programs, prevented static and dynamic tests from being alternated or interspersed randomly. Therefore, it was originally planned to complete all apparatus debugging and calibration in static tests, before dynamic tests were tried. Actually, almost the entire effort was devoted to static tests, and only enough dynamic tests were done to confirm that similar behavior resulted. A data summary of the static tests is listed in Table I, and the summary of the dynamic tests is presented in Table II.

The emphasis and direction of this stage of the program changed as a logical response to certain observations in the earlier tests. From the start, great care was taken to control the uniformity and properties of the soil samples and to operate and align the apparatus to prevent disturbance and misfit. Each sample was to be placed in the apparatus very carefully and tested only once, in its virgin condition. The change in the nature of the planned program consisted in an increase in the intensity with which all such precautions were pursued, to insure that carelessness was not responsible for some of the unexpected observations. The amount of instrumentation was also increased, and some tests were repeated, to insure that the observations were not a result of chance geometry. When the behavior had been demonstrated to be reproducible in static tests, only enough dynamic tests were performed to determine whether it also occurred under these conditions.

TABLE I. Data Summary of Static Tests Measurements at Point of Maximum Applied Load.

Test No.	Soil Type	Density Before (gm/cm^3)	Density After (gm/cm^3)	Sample Height Before (in.)	Sample Height After (in.)	Maximum Applied Load (K lb)	Displacement (in.) Left	Displacement (in.) Rear	Displacement (in.) Right	Measured Loads Moving Piston (K lb)	Measured Loads Fixed Piston (K lb)	Measured Loads Cylinder (K lb)	Radial Load Top (psi)	Radial Load Bottom (psi)	Imbedded Guage Loads Left (psi)	Imbedded Guage Loads Right (psi)	Imbedded Guage Loads Center (psi)	Imbedded Guage Loads Rear (psi)	Teflon Lubricant Used
Table I. Data Summary of Static Tests Measurements at Point of Maximum Applied Load.																			
15	Ottawa Sand	N.R.	N.C.	3-3/8	N.R.	16	0.044	0.036	0.017	19.5	12.3	2.5							
16	Ottawa Sand	N.R.	N.C.	3-3/8	N.R.	12	0.016	0.013	0.048	14.0	8.3	2.2							
17-1	Ottawa Sand	1.82	N.C.	3-1/4	N.R.	10	0.055	0.047	0.026	10.0	E.F.	1.6							
17-2	Ottawa Sand		N.C.	3-9/16	N.R.	10	0.059	0.055	0.034	10.1	E.F.	1.7							
18-1	Ottawa Sand	1.20	N.C.	3-9/16	N.R.	10	0.036	0.018	0.032	11.0	9.5	1.7							
18-2	Ottawa Sand		N.C.		N.R.	10	0.037	0.019	0.034	11.0	9.8	2.1							
19-1	Ottawa Sand	1.76	N.C.	3-7/16	N.R.	10	0.021	0.037	0.022	9.3	8.5	1.8							
19-2	Ottawa Sand		N.C.		N.R.	10	0.026	0.039	0.026	9.5	9.0	1.8							
20	No Data																		
21	Ottawa Sand	1.70	N.C.	3-1/2	N.R.	2.9	0.009	0.015	0.038	2.6	2.3	0.3							
24	Ottawa Sand	1.60	1.66	4-1/32	3-7/8	2.5	0.038	0.014	0.024	2.4	1.9	0.5	13	5.8					
25	Ottawa Sand	1.74	1.75	4-5/16	4-9/32	10	0.030	0.022	0.026	9.6	7.5	2.5	58	37			45		
26	Ottawa Sand	1.72	1.73	4-15/32	4-7/16	3.75	0.039	0.006	0.019	3.6	2.6	1.0	43	28			6		
27	Ottawa Sand	1.74	1.75	4-5/16	4-9/32	10	0.036	0.019	0.027	9.9	6.7	2.9	44	22			8		
28	Ottawa Sand	1.63	1.65	4-3/32	4-1/32	10	0.051	0.037	0.037	10.0	7.4	2.4	41	66			20		
29	Ottawa Sand	1.66	1.68	4	3-15/16	2.5	0.037	0.011	0.010	2.3	1.7	0.6	12	15			5		
30	Ottawa Sand	1.60	1.63	4-1/32	3-31/32	12.8	0.061	0.034	0.051	12.6	9.3	3.4	43	64			41		
31	Ottawa Sand	1.74	1.74	4	3-63/64	10	0.032	0.019	0.020	10.1	7.8	2.1	60	48	24	24			
32	Fine Soil	1.30	N.C.	4-1/8	N.R	10	0.193	0.128	0.170	10.0	7.2	2.7	30	E.F.	49				
33	Fine Soil	1.35	N.C.	3-7/8	3-11/16	10	0.155	0.102	0.132	9.9	7.4	2.5	37	33	61	42			
34	Fine Soil	1.38	N.C.	3-15/16	3-25/32	10	0.147	0.106	0.124	9.7	7.1	2.8	22	21	37	55			
35	Ottawa Sand	1.70	N.C.	4-1/16	3-15/16	10	0.095	0.073	0.079	9.9	9.6	0.5	6	7	70	84			Yes
36	Ottawa Sand	1.70	N.C.	3-15/16	3-13/16	10	[illegible]	0.068	0.077	10.2	9.7	0.6	2	5	70	79			Yes
37	Ottawa Sand	1.78	1.81	3-31/32	3-15/16	10	0.054	0.026	0.033	10.0	7.0	2.9	42	44	16	16			
38	Ottawa Sand	1.70	N.C.	4-31/32	N.R.	10	0.104	0.072	0.085	9.9	9.6	0.5	16	19	96	90			Yes
39	Ottawa Sand	1.58	N.C.	4-3/32	3-7/8	10	0.149	0.094	0.121	9.7	9.3	0.7	5	16	52	88			Yes
40	Ottawa Sand	1.56	N.C.	4-1/8	3-29/32	10	0.159	0.114	0.131	10.2	9.4	0.9	11	19	67				Yes
41	Ottawa Sand	1.79	1.79	4-5/64	4-1/16	10	0.038	0.014	0.032	10.0	7.1	2.9	54	50	12	21			
42	Ottawa Sand	1.79	1.80	4-3/16	4-5/32	10	0.054	0.040	0.041	10.1	7.1	2.8	83	67	14	17		31	
43	Aberdeen Soil	0.85	N.C.	4-1/16	2-11/16	10	0.990	0.972	0.797	9.9	7.7	2.3	17	26	115	98		74	
44	Aberdeen Soil	0.86	N.C.	4-1/16	2-3/4	10	O.S.	0.901	0.751	9.9	7.2	2.6	31	32	126	94		42	
45	Ottawa Sand	1.65	N.C.	4-1/16	N.R.	10	0.109	0.074	0.810	9.9	9.5	0.5	3	7	74	101		67	Yes
46	Ottawa Sand	1.66	N.C.	4-5/16	4-5/32	10	0.123	0.920	0.870	9.9	9.5	0.5	5	8	75	83		56	Yes
47	Ottawa Sand	1.76	1.79	4	3-15/16	10	0.540	0.300	0.280	10.1	6.8	3.1	41	40	27	21		7	
48	Ottawa Sand	1.76	[illegible]	4-5/32	4-3/32	10	0.940	0.710	0.360	9.9	6.6	3.1	E.F	E.F.	7	45		11	
49	Ottawa Sand	1.82	N.C.	5-23/32	5-17/32	10	0.151	0.117	0.121	9.9	9.2	0.9	29	23	98	69		67	Yes
50	Ottawa Sand	1.68	N.C.	5-13/16	N.R.	10	0.149	0.132	0.123	10.1	9.3	0.8	14	7.8	58	98		58	Yes
51	Ottawa Sand	1.69	N.C.	6-3/32	5-29/32	10	0.152	0.133	0.141	10.0	8.9	1.0	21	14	99	[illegible]		58	Yes
52	Ottawa Sand	1.69	N.C.	6-3/32	5-7/8	10	0.149	0.128	0.131	10.0	9.0	[illegible]	27	[illegible]	81	67		55	Yes
Table II. Data Summary of Dynamic Tests Measurements at Peak Dynamic Load.																			
53	Ottawa Sand	1.73	1.79	4-1/4	4-7/32	N.R.				3.2	2.1	1.3	17	16	10	4		2	
54	No Data																		
55	No Data																		
56	Ottawa Sand	1.69	N.C.	6-7/32	N.R.	N.R.	0.109	0.135	0.121	9.9	[illegible]	1.3	24	15	74	79		54	Yes
57	Ottawa Sand	1.68	N.C.	6-1/8	5-15/16	14.5	0.144	0.155	0.133	14.5	14.4	1.4	O.S.	12.5	122	165		115	Yes
58	Ottawa Sand	1.78	N.C.	6-1/32	N.R.	N.R.	0.050	0.055	0.042	15.3	10.9	5.9	E.F.	60.4	65	52		33	

Abbreviations:

N.R - Not Recorded
N.C. - Not Calculable from Data Recorded
E.F. - Equipment Failure
O.S. - Off Scale Reading

One of the more important changes in the program was a reduction in the number of types of soils used in tests. It was felt necessary to limit samples to only those which could be most uniformly and reproducibly placed in the apparatus. However, more than one type of sample was used, to eliminate the chance that the tilting was a phenomenon peculiar to a certain sample only. The samples used are indicated in the second column of Table I, and their properties and method of placement are described below.

The most frequently used type of soil was Ottawa sand, passing the No. 20 but retained on the No. 30 sieve. This soil was most often placed in the oedometer in the dense state, by means of the "raining" technique. In other tests, it was placed more loosely, by careful pouring from a spoon held close to the surface. The densities achieved by these methods are listed in the table, for both the before-and-after test condition. The densities were determined by weighing the amount of soil placed in the oedometer, and by measuring the depth of the sample at several points. The measurement was made by placing a steel straight edge across the top of the cylinder at precise locations marked with a scribe, and measuring down from it to the surface with a ruler. To facilitate the measurement, a plate of thin aluminum sheet was set carefully on top of the sample. From the known weight of soil, and the measured volume it occupied in the oedometer, the density of the entire quantity of soil or of a particular layer or increment could be calculated.

Another type of soil used was the finer fraction of the soil available in sand bars of a small stream draining part of the company's property in Alexandria, Virginia. The sample was prepared by drying followed by passage through a No. 40 sieve. It can be best described as a silty, dirty, fine sand, containing a small proportion of material passing the No. 200 sieve, normally less than 3%, while less than 10% passed the No. 100 sieve. It was always used in the dry condition and placed loosely. The grains of this soil were extremely angular and sharp-cornered, having been produced by erosion very close to the point found.

A further type of soil was the material found at the site of the Ballistic Research Laboratories installation where field tests were performed on soils by BRL personnel. The location is close

to the Chesapeake Bay waterfront of the installation. The soil is a clayey, silty, fine sand, typical of such a beach deposit. It is quite similar to the local Virginia material described above, except for a larger proportion of fine material and less angularity of the grains. In the present case, it was used at the field moisture content, found to be 13% to 14%, but in a disturbed state and at a very low density, produced by forcing it while moist through a No. 4 sieve. This resulted in a flocculated, loose, and open structure.

When such fine soils were used, some technique to keep them from the clearance space between the pistons and the oedometer wall was, of course, necessary. The method used was to provide a layer of Ottawa sand, intended to be one-half inch thick, above and below the layer of finer soil. Consideration of the relative grain sizes indicates that these materials are in proper relation to serve as a filter course for the 0.010 inch clearance. The weight and height of the sand layers and of the other layer were, of course, measured separately, to permit density calculations. The Ottawa sand was "rained" into place in the bottom layer, but the top layer had to be placed in the loosest and gentlest condition because of the possible disturbance and compaction of the very weak and fragile fine soil structure.

In a number of samples, a layer of Teflon powder was placed between the sample and the cylinder wall, to investigate the effect of reducing the side friction. To produce this layer, a jig was used consisting of a sleeve of thin copper sheet 1/2 inch less in diameter than the oedometer's internal diameter. With this sleeve centered in the oedometer, soil was placed within the sleeve and Teflon powder in the annular space in shallow layers, as low as 1/4 inch in the case of denser soil samples, and the sleeve was withdrawn with care for that height before the next layer was added. In Figure 6 the typical state of the Teflon powder after a test is shown. After compression the Teflon was firmly compacted and adhered to the oedometer wall, as shown.

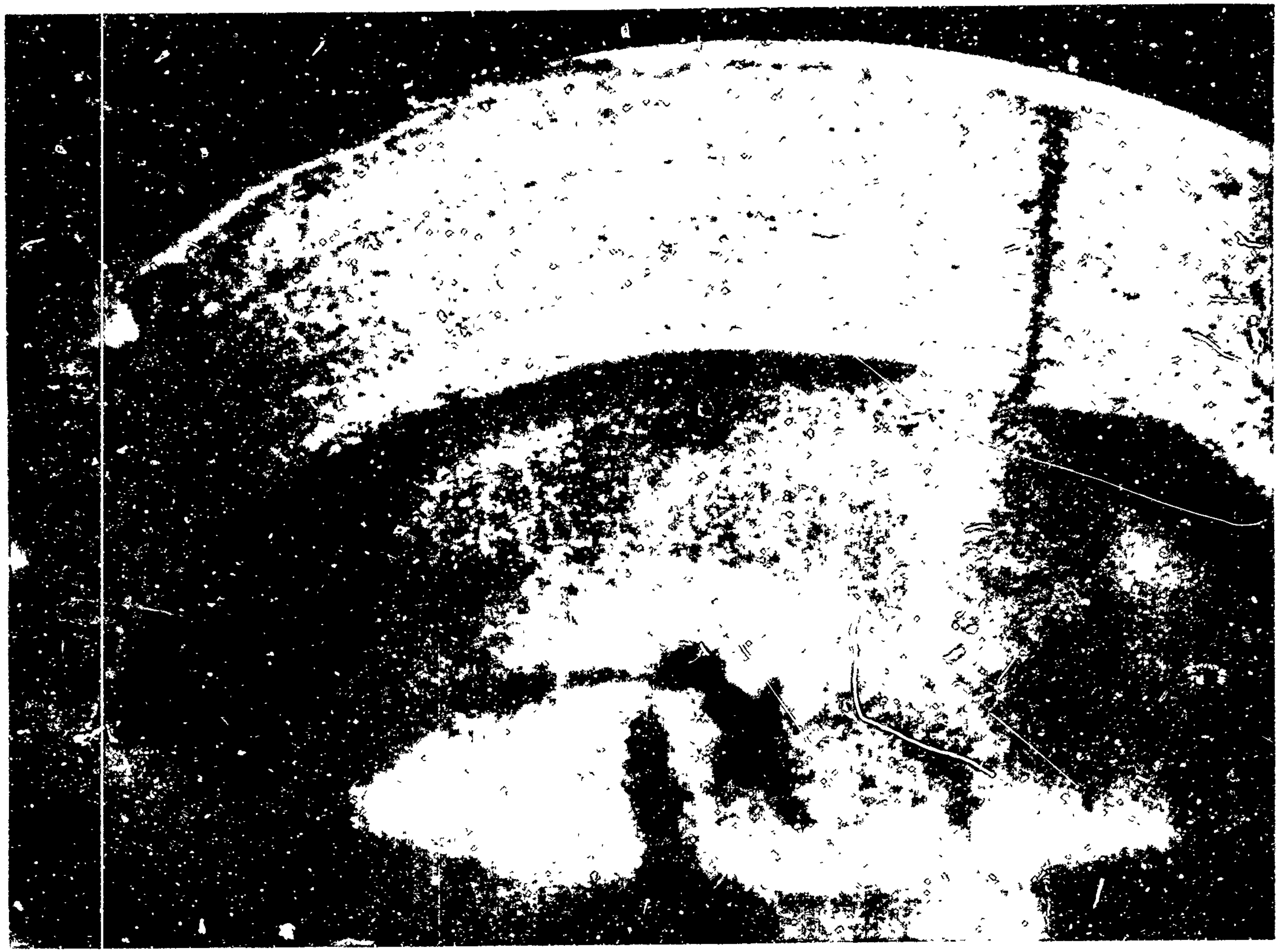

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Figure 6. Molding of Teflon Powder Lubricant After Loading.

Except for two cases where failures of electronic channels were being checked, each sample was subjected to load only once, and was then removed from the oedometer. Care was taken, of course, to record the before and after density, height, and visual evidences of tilt where such were observed. As noted, however, visual evidence of tilt was found very difficult to photograph.

During the program, 58 sets of data were recorded. Of these, 15 were basic calibrations of the oedometer and its associated instrumentation. Of the 43 actual tests, 37 were performed under static loading conditions and the remaining six were run under dynamic loading conditions, using the Hyge Shock Tester.

Twenty-nine of the static tests were completely successful and 7 were partially successful when considered from the standpoint of data output. One of the six dynamic tests appears to have been completely successful and three appear to have been partially successful. In the remaining tests, no useable data were recorded.

Under all test conditions, the data from the LVDT's indicate a tilting of the movable piston. In all but three of the static tests, the data indicated that the same point on the movable piston underwent the greatest displacement. These three tests were among the first six performed.

Under the dynamic loading conditions, the movable piston was again tilted, but the point of greatest displacement was different than in the static tests.

Table I is a brief summary of the static tests. The data listed in the table are for the condition of maximum applied load. The data in Table II are the recorded values of the various parameters at peak dynamic load. It will be noted that several numbers are missing from the series of test numbers. These numbers were used for instrumentation calibration.

Complete data for all the tests are listed in the appendix.

4.0 TYPICAL TEST DATA

4.1 Static Tests

Two basic sets of static tests were conducted during the program. The only difference between the test procedures was the use of a Teflon powder lubricating layer in one set of tests. The soil samples used in these tests were both Ottawa sand, but as noted on the curves, there were small differences in the densities and original heights of the samples. Because of this, an absolute correlation of the two tests cannot be achieved; however, since these tests are very similar to the other tests in the series, generalized trends can be studied.

Figure 7 presents curves of 11 parameters plotted against the applied static load. This particular sample had an original density of 1.76 gm/cm^3 and an original height of 4 inches. The final density was about 1.79 gm/cm^3, and the total permanent compression approximately 1/16 of an inch.

The relative positions of the LVDT's and the imbedded gages are shown in the sketch at the right side of the figure. The curve marked "upper strain gage" is a measure of the radial stress in the soil sample near the top of the cylinder, while the "lower strain gage" curve is a similar measurement made near the base of the cylinder.

From the first application of load, a relatively large difference is noticed in the loads as measured by the moving and fixed pistons. This difference is approximately equal to the value of the axial load in the cylinder. It is also noted that during the initial loading period, the force measured by the moving piston is less than the applied load. At the initial point of loading, an extremely large discrepancy is observed in the displacements of the three LVDT's. This difference persists throughout the tests. The three imbedded gages also show large differences in output, as well as anomalously low stress levels. In this test, the upper and lower strain gages measuring the radial stress in the soil are in reasonably good agreement. (This is not completely typical of the test series.)

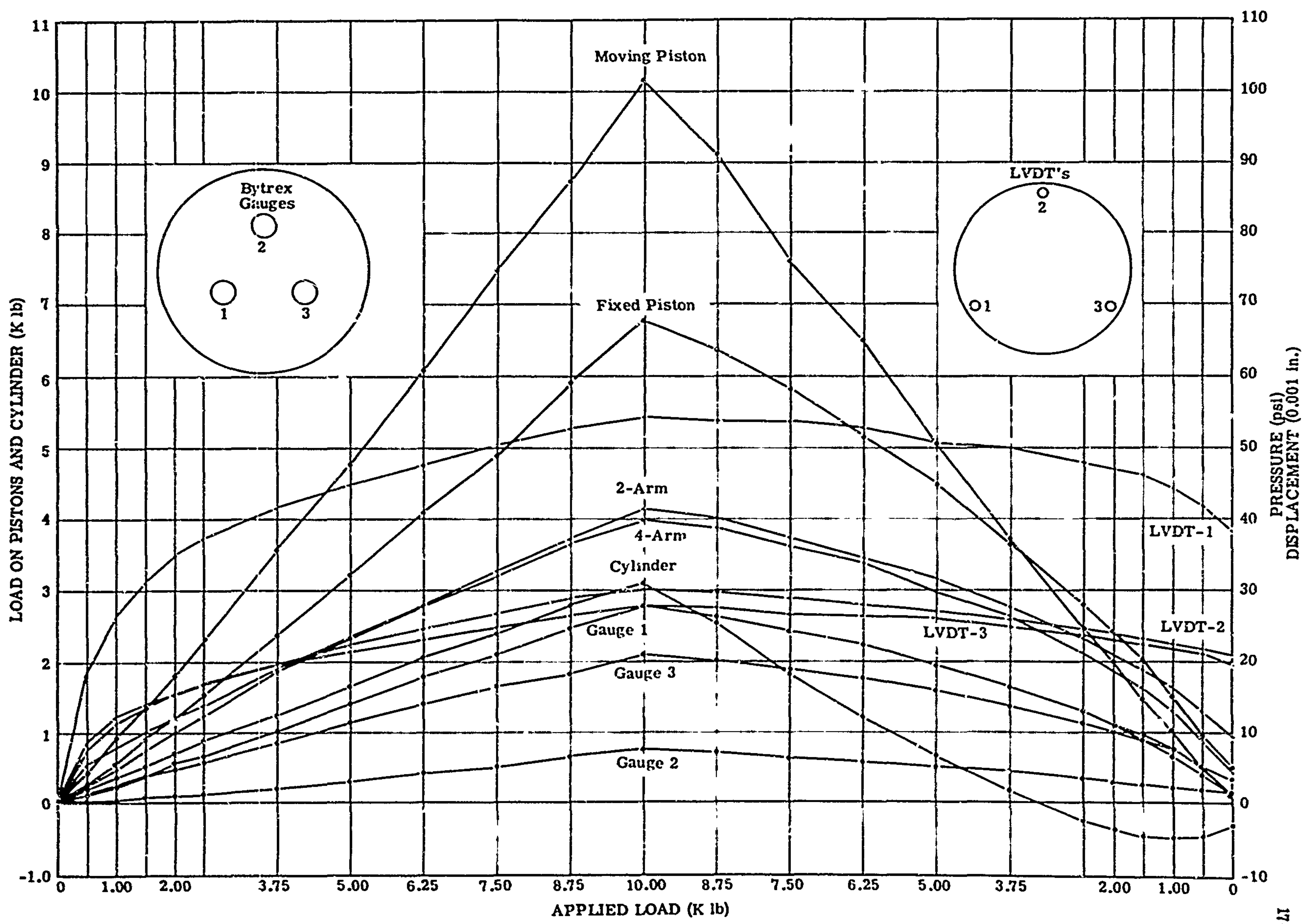


Figure 7. Typical Static Test, Ottawa Sand Without Teflon Powder Lubricant.

As the load is reduced on the sample, it is noted that the compression of the soil is decreased as is expected, and that the amount of elastic recovery is somewhat proportional to the maximum displacement. The most interesting phenomenon observed during this relaxation period is that a point is reached at which the load on the fixed piston exceeds the load on the moving piston, which is approximately equal to the applied load. At approximately this same point the axial load in the cylinder becomes negative, indicating that the load columns supporting the cylinder have gone into tension.

Figure 8 presents data from Test 46 which is quite similar to that discussed above. The original soil density was 1.66 gm/cm^3 and the original sample height was 4 5/16 inches. The total permanent compression was approximately 5/32 of an inch. The major difference between this and the preceding test was the use of a Teflon powder lubricating layer between the sample and the cylinder wall.

The discrepancy in the displacement measurements was similar to that noted in previous tests. Several very significant changes were noted in this test. There was much closer agreement between the loads measured on the fixed and moving pistons accompanied by a corresponding decrease in the cylinder axial load. The stresses measured by the imbedded gages, while not at all in agreement were much higher than in the previous test, and the radial stresses in the soil as measured by the upper and lower strain gages were greatly decreased and not nearly as well in agreement.

The phenomenon of the pressures on the fixed and moving pistons observed in the previous test during the relaxation of the load recurred but on a much smaller scale.

4.2 Dynamic Tests

Only six dynamic tests were attempted during the program. Of these, two were complete failures in that no data was obtained. Three of the remaining tests had a failure in one or more data channels.

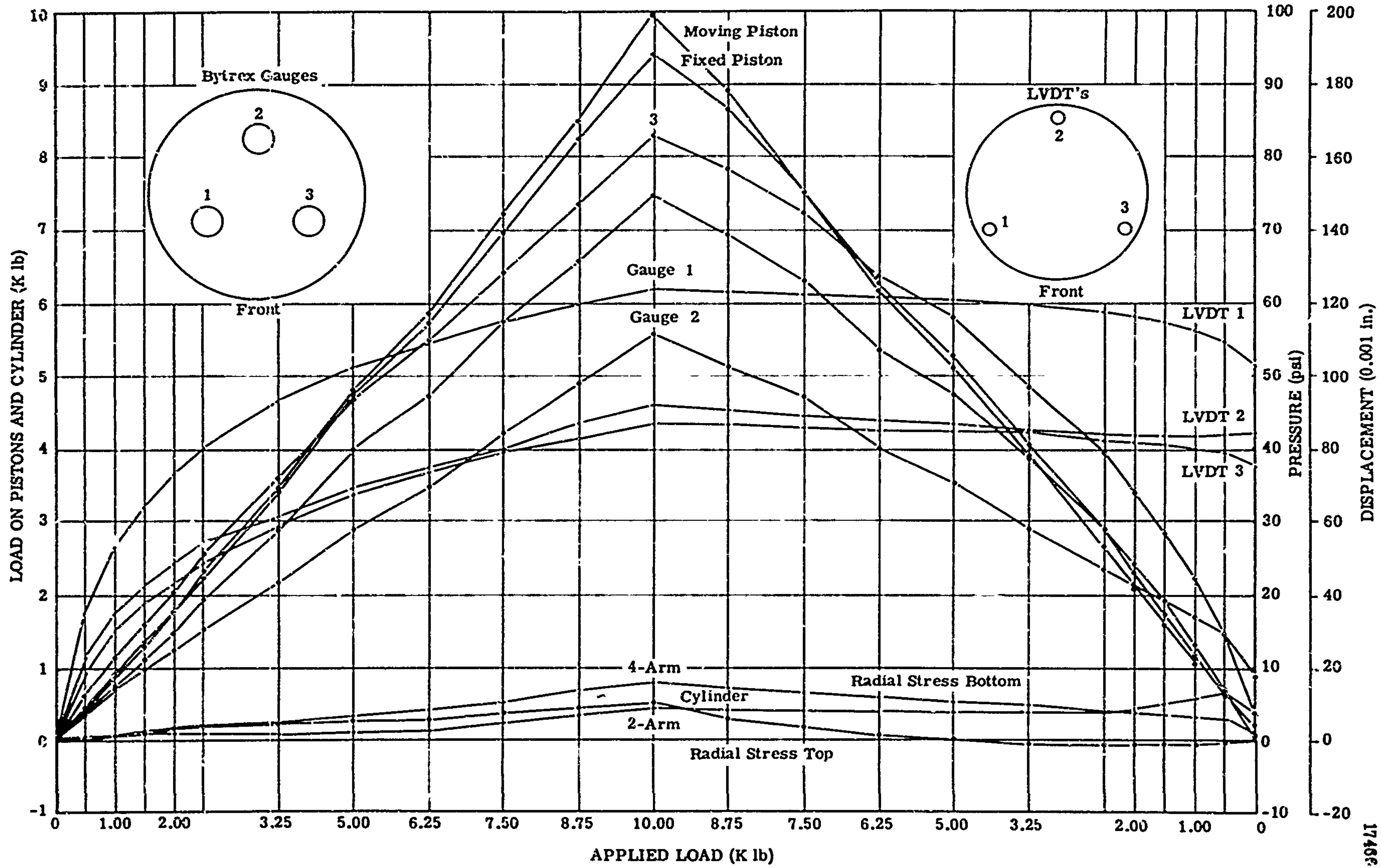


Figure 8. Typical Static Test, Ottawa Sand with Lubricant.

The data of these tests are listed in Table II. Two successful tests were performed without the use of the Teflon powder lubricating layer. In the last three tests, the height of the soil sample was greater than that used in all but the two final static tests.

Test 56 compares reasonably well with Tests 51 and 52. The only major change is the greater frictional force measured in the cylinder.

Tests 52, 57 and 58 cannot be easily compared with any of the static tests because of the magnitude of the load applied to the sample.

In these tests, the exact values of loads reported are somewhat questionable. The rise times of the pulses were very short and there was a tendency for some of the traces to overlap, thereby making it extremely difficult to determine precisely the peak values.

5.0 OBSERVATIONS

5.1 Piston and Cylinder Loads

In general, the applied load as measured by the load cell and the load measured by the strain gage bridge attached to the upper piston do not agree too well. Normally the load measured on the piston is lower than the applied load by up to 5% as the load is increased from zero. In some of the tests, good agreement is achieved when the applied load is in the 5000 to 7500 pound range. In approximately 25% of the tests, the peak load measured by the moving piston was in excess of the applied load, but in most of these cases it is felt that this difference is within the measurement accuracy of the system.

In the tests run with no lubricating layer to reduce the side wall friction in the oedometer, it appears that a large percentage of the applied force is transferred to the cylinder. In all but a few cases, the magnitude of this friction force was 20% to 31% of the applied force.

When a Teflon lubricating layer was utilized, the frictional force was reduced to a value of between 5% and 10% of the applied load.

In tests 15 through 20 (see complete data in Appendix), the values of the friction forces reported are generally lower than those measured in the remainder of the tests. On review of the original data sheets, some question is raised as to the validity of the initial calibration check run before each test.

In all the tests, it was observed that as the load was relaxed, a point was reached when the force on the fixed piston exceeded the force on the movable piston. At approximately the same point, the axial cylinder load became negative. In most tests, the difference between the force on the movable and fixed piston is about the same as the negative load on the cylinder. It was also noted that the load on the fixed piston was greater than the applied load.

A possible explanation exists for this phenomenon. As the axial load was increased to a maximum, the radial stress also increased to a maximum, but as the axial load was reduced to zero, the radial load decreased, but approached some final values. This residual radial stress creates a friction force tending to raise the cylinder, thus transferring the cylinder weight to the fixed piston along with part of the bolt tension in the cylinder load columns.

5.2 Cylinder Radial Loading

The radial loading in the cylinder was greatly decreased by the use of Teflon powder. This powder was loosely placed between the cylinder and the sample. It is believed that the powder was so loose that it compacted due to radial displacement in the sample. This allowed the sample to strain appreciably in the lateral direction without creating a true force indication in the cylinder wall, thus destroying the one-dimensional character of the tests. This is similar to what one would expect if the sample were confined in a flexible cylinder, since the load carrying (or transmitting) ability of the Teflon is very small compared to the cylinder.

It is believed that the radial force measured when Teflon was used is not an accurate measure of the strain and therefore is not useful for computing Poisson's ratio.

In the tests performed without the use of Teflon, the radial loading measured was considerably higher, but because of the frictional forces a state of one-dimensional stress suitable for computing Poisson's ratio was not achieved.(1) It is believed that this effect may be considerably reduced by decreasing the volume of Teflon.

5.3 Piston Displacement

When the compression of the soil sample measured by the LVDT was compared with the depths recorded before and after a test, Tables I and II, it was noted that the LVDT's generally indicated a lower compression than was measured manually. It is felt that this discrepancy is in part due to some initial unrecorded compression during placement of the piston and the loading apparatus. In Test No. 43, when a very low density soil was used, a compression of approximately 3/8 of an inch was recorded during placement of the piston and ram. During Test No. 44, a compression of 1/2 inch was recorded during this initial period.

With the higher density soils, it is believed that this initial compression during placement of the loading appartus was so small that it was not readily observed by the personnel running the tests, and therefore, was not recorded.(1)

The displacements recorded in Tables I and II are the maximum displacements under load. As the load was decreased on the sample, the displacement also dropped to a lower value in all tests except No. 43 and No. 44. In view of this fact, it is felt that some other factor(s) must have an effect on the displacement discrepancy. One factor could be the method of measuring the soil depth before and after the test. The tolerance involved in this measurement tecnnique was about ± 1/64 inch.

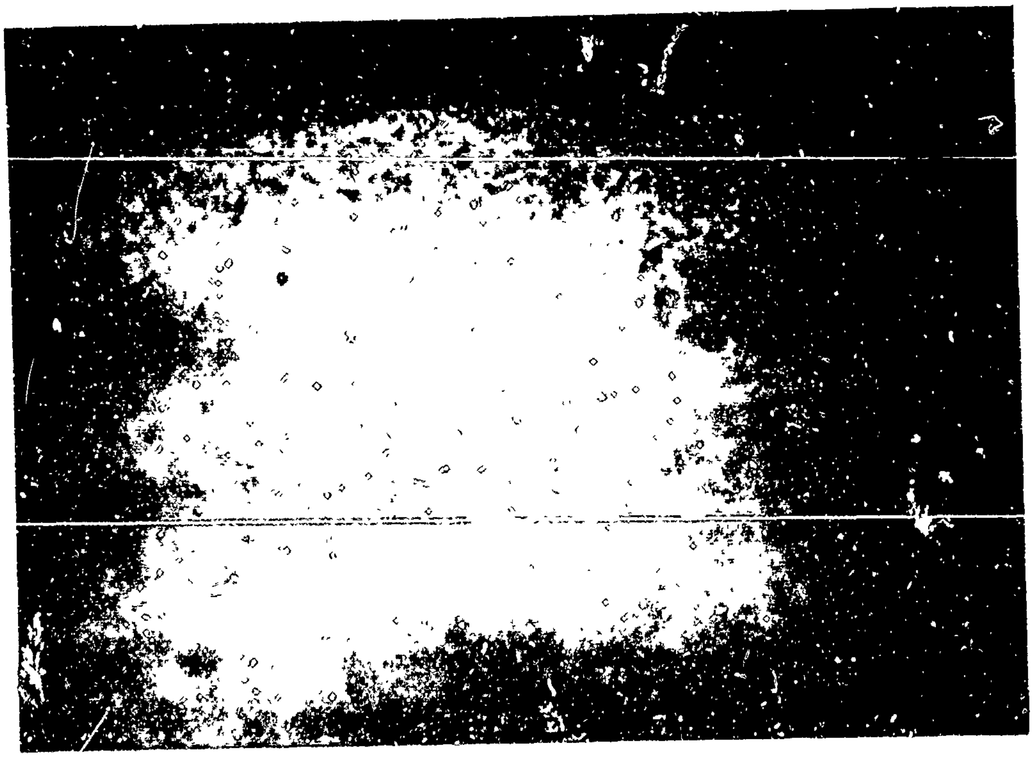
(1) "Two dimensional wave propagation experiments in soils" - prepared under Aberdeen Contract R6219.

During the testing, a tilt of the movable piston assembly under load was quite pronounced. It was indicated in two ways. The most certain indication was a difference in the output signal of the LVDT's measuring the vertical travel of different points on the assembly. The other was a pattern which was found on the surface of a number of samples when the upper piston was removed after a test. This pattern was a fine ridge on the surface of the sample near its edge and extending for some distance around its circumference. The pattern was difficult to photograph, as can be seen from Figure 9. The photographer's difficulty arose principally from the extent to which the apparatus limited the space and geometry within which the lights and camera could be arranged, although the pattern was quite visible to the naked eye. The sight of this obvious pattern first led to the speculation that tilting of the piston might be occurring, and thus caused the test procedure and apparatus to be modified and extended to permit checking of this tilting.

5.4 Imbedded Gages

The original dimensions of the oedometer were chosen so that the height/diameter (H/D) ratio of the soil specimen could be made quite small. By so doing, the expected high friction forces at the soil-cylinder boundary could not have a major effect on the central area of the soil where the gages are imbedded. The stress state on the gages should thus be nearly one-dimensional However, the measurements made by the imbedded gages in the test without Teflon show values considerably lower than the average pressure applied to the sample. This might result from certain arching effects across the gages, or it might reflect an effect of side friction because the three gages were actually placed outward from the center area. However, the same trend was observed in Tests 25 through 30 when one gage was placed at the center of the sample, and in Tests 31 through 40 when two gages were placed on a single diameter about 3 inches on each side of the axis of the oedometer. To determine if this were so, further tests - with varying H/D ratios - should be made for comparisons.

Figure 9a. View of Sand Ridge Formed on Upper Surface of Soil Sample.



17406

Figure 9b. View of Sand Ridge Formed on Upper Surface of Soil Sample.

Figure 9a and 9b. Two Views of Sand Ridge Formed on Upper Surface of Soil Sample.

No conclusions can be drawn from the fact that gage measurements made with the Teflon present were considerably closer to the applied load. Too much radial strain occurred, and the one-dimensional state of stress was no longer present.

The highest readings recorded by the imbedded gages occurred during Tests No. 43 and 44 when Aberdeen soil was used. As was stated previously, this soil was very fine and was less angular than the other soils tested. It is felt that these properties, coupled with the fact that soil was placed in the oedometer in a very low density state (0.8 gm/cm^3), allowed the soil to strain appreciably in the lateral direction, thus eliminating the tendency of the soil to bridge over the gages. The angularity of the soil particles may be the most important factor in determining the ability of soils to arch or bridge.

6.0 DISCUSSION OF RESULTS

In the course of the test program, it became apparent that a true one-dimensional state of stress could not be achieved with the present oedometer design.

The use of Teflon powder as a lubricant did reduce the frictional forces in the oedometer, but introduced lateral strains too large for one-dimensional conditions to be maintained.

Tilting of the upper piston with load application was a second factor contributing to the lack of one-dimensionality in the oedometer. The causes of the tilting could have been (a) binding of bearings on the guides, (b) inaccurate alignment of the guide assembly and/or loading apparatus, (c) binding of the piston, and (d) variation in height across the surface of the sample. The consistency of direction of tilt in various tests of one type of loading leads one to discount the last two possibilities (which would have caused random tilting). Future testing with the oedometer must include instrumentation to determine the cause of the tilt, and modifications to eliminate it.

7.0 SUMMARY

A series of tests using the dynamic oedometer filled with a number of different sand types has been performed. During these tests, difficulty was encountered in maintaining a one-dimensional state of stress in the region of the sand mass where the gages were inbedded. The causes of the difficulty were (a) tilting of the piston head, (b) side friction effects and (c) lateral expansion into the Teflon powder when this was used to reduce the friction effects. Until these problems can be solved, the oedometer will not be suitable for the stated purposes of gage calibration and measurement of the soil constants necessary for propagation prediction.

8.0 RECOMMENDATIONS

Although the test series discussed in this section of the report did not achieve the desired results, it did point out the difficulties involved in attempting to simulate a condition of one-dimensional stress in the laboratory.

Before the dynamic oedometer is "written off" as a useful laboratory instrument, further effort should be expended to determine the cause of the tilting of the upper piston. Once this problem has been solved, a series of tests should be performed with varying height-to-diameter ratios to determine if the friction effect can be sufficiently reduced without the use of a lubricant. In the performance of these tests, gage locations should be selected so that a profile of readings across the oedometer could be obtained.

If the friction effects can not be sufficiently immunized by the proper choice of H/D ratio, a test series should be performed to determine if varying the thickness and/or density of the Teflon powder lubricant would result in a one-dimensional state of stress.

APPENDIX

DYNAMIC OEDOMETER TEST DATA

APPENDIX

GENERAL:

The following pages are a complete tabulation of all data recorded during the test program.

At the top right hand corner of each data sheet, a pair of sketches, showing the approximate angular position of the imbedded gages and the linear variable differential transformers, is provided so that gage readings and displacements can be correlated.

In the tests using one imbedded gage, the gage was positioned at the approximate center of the sample. When more than one gage was used, the gages were positioned angularly as shown at a radius of approximately 3 inches (1/2 the radius of the oedometer).

Tests 15 through 52 are static tests. Tests 53 through 58 are tests under dynamic loading. In the dynamic tests, the first line of data is under peak loading conditions and the second line is a steady state condition.

TEST NUMBER 15 DATE 1/10/66

SAMPLE DESCRIPTION Ungraded Ottawa Sand

SAMPLE DENSITY: BEFORE LOADING NR

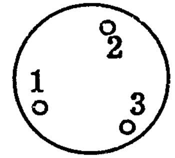
AFTER LOADING NR

SAMPLE HEIGHT: BEFORE LOADING 3-3/8 inches

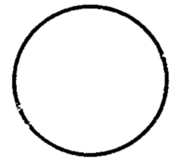
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS: Test stopped at 16000-lb load because of tilting of moving piston.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	NR	NR			
4	4500	2500	500	25	21	6					
8	9000	5500	1500	33	28	11					
12	13500	9000	2000	38	31	14					
16	19000	12000	2500	44	36	17					
12	14000	10500	1500	41	34	16					
8	9000	7000	500	38	31	14					
4	5000	5000		35	29	12					
0	0	500	0	17	15	7	NR	NR			

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TEST NUMBER 16 DATE 1/11/67

SAMPLE DESCRIPTION Ungraded Ottawa Sand

SAMPLE DENSITY: BEFORE LOADING NR

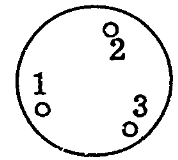
AFTER LOADING NR

SAMPLE HEIGHT: BEFORE LOADING 3-3/8 inches

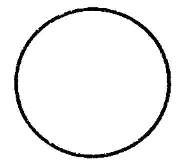
AFTER LOADING NR

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	NR	NR			
5	5750	3500	1000	34	9	37					
8	9250	6500	1500	41	10	43					
12	14000	8250	2250	47	13	49					
8	9250	6500	1250	43	12	46					
4	5250	4250		39	10	43					
0	0	250	0	19	8	23	NR	NR			

TEST NUMBER 17 DATE 2/16/66

SAMPLE DESCRIPTION Ungraded Ottawa Sand

Grain Size > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING $1.82\ gm/cm^3$

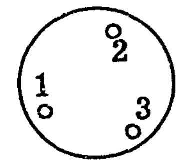
AFTER LOADING NC

SAMPLE HEIGHT: BEFORE LOADING 3-1/4 inches

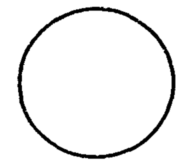
AFTER LOADING NR

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
0	0	0	0	0	0	0					
2.5	2320	2100	550	32	30	19					
5	4640	4270	740	44	41	22					
7.5	7360	6110	1170	50	47	24					
10	10000	EF	1600	55	47	26					
7.5	7620		740	54	47	25					
5	4990		620	50	48	25					
2.5	2500		185	47	43	24					
0	0		60	31	27	25					
2.5	2230		370	46	38	30					
5	4640		820	30	44	31					
7.5	7220		1230	54	55	33					
10	10180		1670	59	47	34					
7.5	7500		740	57	45	34					
5	4820		0	54	43	33					
2.5	2320		-370	50	44	32					
0	0	EF	-60	38	29	31					

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TEST NUMBER 18 DATE 2/17/67

SAMPLE DESCRIPTION Ungraded Ottawa Sand

Grain Size > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING $1.70\ gm/cm^3$

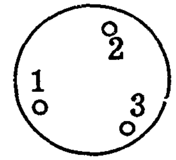
AFTER LOADING NC

SAMPLE HEIGHT: BEFORE LOADING 3-9/16 inches

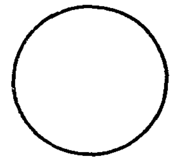
AFTER LOADING NR

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS: Calibration of gauges measuring radial load is questionable.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	[illegible]	0	0	0	0	0	0	0			
2.5	2800	2200	560	21	9	12	27	12			
5	5300	4400	1000	28	12	24	45	23			
7.5	9000	7000	1400	33	16	28	59	32			
10	11000	9500	1750	36	18	32	72	40			
7.5	6200	8000	810	36	17	30	70	36			
5	5500	5900	0	33	16	28	64	31			
2.5	2900	3300	-440	30	14	25	50	24			
0	330	250	-80	20	11	15	10	4			
2.5	3200	2500	500	28	13	24	15	8			
5	5600	4800	1100	31	15	27	27	17			
7.5	8200	7300	1500	34	17	30	39	22			
10	11000	9800	2100	37	19	34	50	31			
7.5	8500	8000	1000	36	17	32	48	26			
5	5800	6100	190	35	17	30	45	24			
2.5	3200	3800	-250	32	15	28	36	17			
0	1300	420	60	22	12	17	4	1			

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TEST NUMBER 19 DATE 2/21/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787 > Grain Size > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING $1.76\ gm/cm^3$

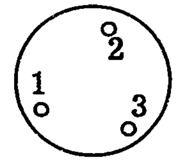
AFTER LOADING NC

SAMPLE HEIGHT: BEFORE LOADING 3-7/16 inches

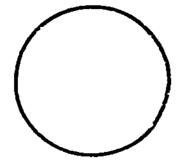
AFTER LOADING NR

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS: Calibration of gauges measuring radial load is questionable



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0			
2.5	2210	2080	490	7	18	12	1	7			
5	4590	4310	925	14	26	7	4	13			
7.5	7000	6340	1300	18	31	20	3	19			
10	9350	8460	1790	21	37	22	2	25			
7.5	7030	6920	926	20	35	21	4	22			
5	4670	5080	309	18	31	20	4	18			
2.5	2130	2540	247	14	28	18	4	11			
0	-82	154	0	10	18	14	3	2			
2.5	2130	2080	555	18	28	20	3	8			
5	4510	4150	989	20	32	22	1	15			
7.5	7030	6210	1480	23	37	24	-1	20			
10	9510	9000	1910	26	39	26	3	26			
7.5	7120	6920	989	25	37	25	-3	24			
5	4670	5150	247	23	36	24	-1	20			
2.5	2290	3000	-247	20	33	23	1	14			
0	0	231	0	14	21	17	3	3			

F390-1-68

TEST NUMBER 21 DATE 2/23/67

SAMPLE DESCRIPTION Graded Ott: va Sand

0.0787 inch > Grain Size > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING $1.69\ gm/cm^3$

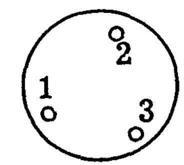
AFTER LOADING

SAMPLE HEIGHT. BEFORE LOADING 3-1/2 inches

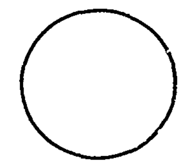
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS: Calibration of gauges measuring radial load is questionable. Measurements at 1.02 K-lb load also questionable.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0			
0.46	328	308	62	0.5	3.8	8.3	3.9	3.6			
1.02	574	385	185	2.9	7.8	16.7	7	6.8			
1.63	1480	1230	247	5.6	9.6	23.7	9.5	9.4			
2.90	2630	2310	309	9.2	15.1	34.4	14.7	14.4			
1.51	1480	1390	62	8.3	13.5	32.4	6.0	7.5			
1.11	1070	1080	0	8	13	31.3	2.6	4.8			
0.46	410	462	-62	7.6	11.4	28.3	-2.9	0.4			
0	0	0	-62	8.5	7.8	21.2	5.2	-2.3			

F390-1-68

TEST NUMBER 24 DATE 2/24/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787 inch > Grain Size < 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING 1.60 gm/cm^3

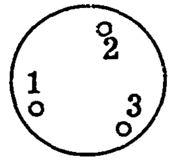
AFTER LOADING 1.66 gm/cm^3

SAMPLE HEIGHT BEFORE LOADING 4-1/32 inches

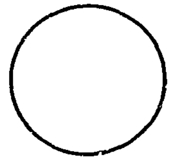
AFTER LOADING 3-7/8 inches

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS: Moving piston appeared tilted before load was applied



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0			
0.5	345	312	116	18	7	15	2.9	0.9			
1.0	776	704	232	31	9	18	5.7	2.0			
1.5	1293	1094	291	33	12	21	8.4	3.0			
2.0	1897	1485	407	35	14	22	10.5	4.4			
2.5	2415	1875	523	38	15	24	13.1	5.8			
2.0	1982	1640	291	38	14	23	12.0	5.2			
1.5	1638	1407	116	37	14	23	11.3	4.6			
1.0	1034	1094	0	35	13	22	8.9	3.1			
0.5	604	625	-58	33	13	22	6.3	1.8			
0	0	78	-58	27	14	18	3.4	1.0			

F390-1-68

TEST NUMBER 25 (Sheet 1 of 2) DATE 3/1/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787 inch > Grain Size > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING 1.74- gm/cm^3

AFTER LOADING 1.74+ gm/cm^3

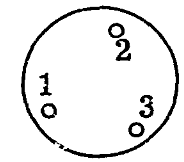
SAMPLE HEIGHT: BEFORE LOADING 4-5/16 inches

AFTER LOADING 4-9/32 inches

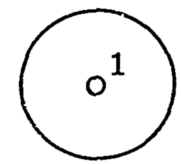
HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

2 inches

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
0	0	0	0	0	0	0	0	0	0		
0.5	446	336	117	8.5	8.5	8.8	2.9	3.3	2.1		
1.0	892	756	292	12.9	11.4	12.1	6.8	6.3	5.3		
1.5	1428	1176	409	15.3	13.5	14.1	10.8	9.1	8.1		
2.0	1874	1512	526	17.0	14.2	15.4	14.4	11.4	11.1		
2.5	2231	1764	643	17.9	15.0	16.3	16.8	12.9	13.3		
3.75	3570	2772	936	20.8	17.3	18.9	25.2	18.1	19.2		
5.0	5087	3948	1345	23.7	18.6	20.8	34.1	23.2	26.2		
6.25	6069	4704	1579	25.2	19.5	22.3	38.9	26.3	29.8		
7.5	7229	5544	1930	26.8	20.3	23.5	44.9	29.8	31.3		
8.75	8434	6552	2223	28.2	21.2	24.6	51.2	33.5	39.9		
10.0	9639	7560	2574	29.7	22.1	25.8	57.8	37.4	45.2		
8.75	8434	6930	1872	29.2	20.8	25.4	53.6	35.4	42.1		
7.5	7363	6426	1287	28.7	19.9	25.4	51.2	34.1	39.9		
6.25	6069	5880	702	27.8	19.5	24.6	48.0	31.5	36.9		
5.0	5087	5208	351	27.3	18.6	24.2	44.1	29.3	33.4		
3.75	3481	4032	0	25.8	16.9	23.1	36.2	25.4	27.5		

TEST NUMBER 25(Sheet 2 of 2) DATE 3/1/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

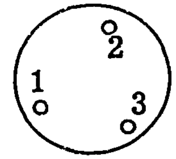
AFTER LOADING

SAMPLE HEIGHT BEFORE LOADING

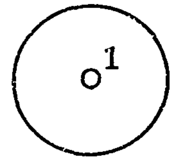
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
2.5	2321	3108	-292	24.4	15.8	22.0	28.4	21.4	22.2		
2.0	1963	2772	-409	24.4	15.1	21.6	26.8	20.5	20.8		
1.5	1428	2268	-468	23.4	13.8	20.8	20.9	17.8	17.5		
1.0	892	1512	-468	22.3	11.9	20.1	15.8	14.4	13.3		
0.5	446	1008	-292	20.4	9.7	18.9	9.2	9.8	8.6		
0	0	336	-175	18.3	5.8	16.9	3.9	4.6	3.2		

F390-1-68

TEST NUMBER 26 DATE 3/2/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787 inch > Grain Size < 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING 1.72 gm/cm^3

AFTER LOADING 1.73 gm/cm^3

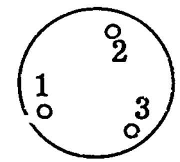
SAMPLE HEIGHT: BEFORE LOADING 4-15/32 inches

AFTER LOADING 4-7/16 inches

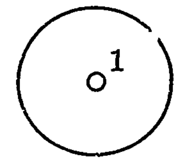
HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

2-1/4 inches

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0		
0.5	452	331	122	20	5	8	8	5	0.6		
1.0	996	662	245	27	6	11	16	10	1		
1.5	1538	1241	245	34	6	15	27	17	3		
2.5	2353	1655	674	35	6	16	33	20	4		
3.75	3620	2565	980	39	6	19	43	28	6		
2.5	2353	2069	368	38	5	19	38	24	5		
2.0	1900	1820	184	37	4	18	35	22	4		
1.5	1358	1490	0	37	4	17	31	20	4		
1.0	905	1158	-184	35	3	16	25	17	3		
0.5	362	662	-245	34	2	15	18	12	2		
0	0	166	-184	29	0	15	7	4	1		

TEST NUMBER 27 (Sheet 1 of 2) DATE 3/2/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787 inch > Grain Size > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING 1.74 gm/cm^3

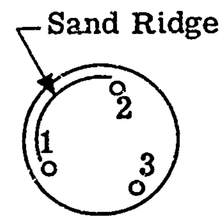
AFTER LOADING 1.75 gm/cm^3

SAMPLE HEIGHT: BEFORE LOADING 4-5/16 inches

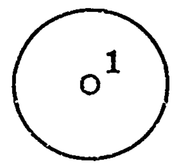
AFTER LOADING 4-9/32 inches

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS: Ridge of sand noted after test on surface in position shown by Atlantic Research LVDT Location Sketch.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0		
0.5	402	179	226	8	1.7	4	0	-0.1	0.2		
1.0	902	478	406	13.8	3.8	8.1	2.4	0.8	0.6		
1.5	1368	807	565	17.0	5.3	10.2	4.2	1.8	0.8		
2.0	1868	1196	678	19.7	6.7	12.1	6.3	2.8	1.2		
2.5	2334	1435	846	21.5	7.8	13.8	8.4	3.9	1.5		
3.75	3542	2317	1188	25.1	10.3	16.9	14.2	7.0	2.4		
5.0	4830	3199	1581	27.9	12.5	20.0	20.1	10.2	3.5		
6.25	6182	4096	1920	30.6	14.3	21.7	25.6	13.1	4.6		
7.5	7342	4963	2260	32.3	15.8	23.9	31.5	16.2	5.8		
8.75	8694	5830	2600	34.1	17.4	25.5	37.8	19.0	7.0		
10.0	9918	6728	2940	35.6	18.7	27.0	44.1	22.0	8 3		
8.75	8694	6167	2315	35.1	18.2	26.5	38.4	19.9	7.5		
7.5	7583	5741	1718	34.8	18.2	26.0	35.2	18.4	6.8		
6.25	6279	5247	1018	34.1	17.5	25.4	31.5	16.3	6.0		
5.0	5055	4560	452	33.6	16.3	24.6	27.8	14.2	5.4		
3.75	3735	3797	0	32.6	15.6	23.2	2.4	11.7	4.4		

F39C-1-68

TEST NUMBER 27 (Sheet 2 of 2) DATE 3/2/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

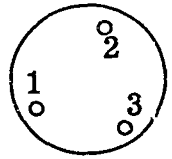
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

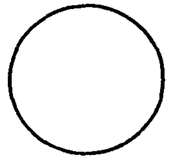
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
2.5	2415	2990	-282	31.0	14.5	21.6	16.8	8.7	3.5		
2.0	2093	2332	-406	30.4	13.5	20.9	14.9	7.7	3.1		
1.5	1610	2093	-452	29.2	12.8	19.7	12.9	6.2	2.7		
1.0	1046	1644	-452	27.8	11.9	18.4	11.0	4.6	2.1		
0.5	644	1046	-361	25.3	11.1	16.9	9.4	2.9	1.5		
0	80	224	-113	17.9	11.4	12.6	6.8	1.1	0.5		

TEST NUMBER 28 (Sheet 1 of 2) DATE 3/3/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787" > Grain Size > 0.0165"

SAMPLE DENSITY: BEFORE LOADING 1.63 gm/cm^3

AFTER LOADING 1.65 gm/cm^3

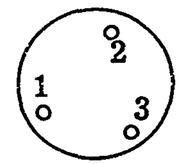
SAMPLE HEIGHT BEFORE LOADING 4-3/32 inches

AFTER LOADING 4-1/32 inches

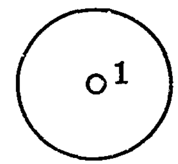
HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

2 inches

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	DISPLACEMENTS LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	RADIAL LOADS TOP psi	BOTTOM psi	IMBEDDED GAGE LOADS NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0		
0.5	510	325	120	19.0	14.0	14.1	7.1	3.5	0.6		
1.0	935	650	240	25.2	17.6	17.4	12.1	6.2	1.2		
1.5	1360	975	360	29.2	19.9	20.5	17.1	8.8	2.1		
2.0	1870	1381	480	32.1	22.1	22.3	21.3	11.2	3.0		
2.5	2380	1788	600	34.3	23.8	23.9	24.8	13.1	4.1		
3.75	3570	2681	900	38.7	27.2	26.9	33.6	18.4	6.6		
5.0	4845	3656	1200	42.4	29.7	30.3	41.7	23.6	9.3		
6.25	6120	4631	1500	44.6	32.1	32.3	48.8	28.4	12.2		
7.5	7395	5525	1740	47.5	33.9	33.8	56.4	32.2	14.9		
8.75	8670	6581	2100	48.7	35.7	35.4	63.0	36.8	17.8		
10.0	10030	7434	2400	49.9	36.9	36.9	68.2	41.3	20.5		
8.75	8798	6825	1860	51.1	36.3	36.4	64.3	38.1	19.0		
7.5	7522	6216	1140	50.4	35.7	36.4	63.0	35.4	17.5		
6.25	6120	5769	660	49.7	35.7	35.9	56.7	32.2	15.6		
5.0	4930	4794	240	48.9	35.1	34.8	51.2	29.3	13.5		

F390-1-68

TEST NUMBER 28 (Sheet 2 of 2) DATE 3/3/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

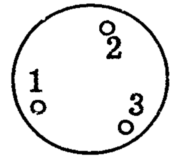
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

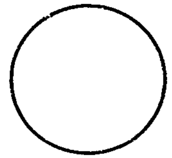
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
3.75	3655	3981	-120	47.5	33.3	34.3	44.9	24.9	11.7		
2.5	2380	2925	-360	45.3	32.7	32.8	36.2	19.3	9.0		
2.0	1870	2438	-420	45.3	31.5	32.3	31.5	17.2	7.7		
1.5	1445	1869	-420	43.8	30.3	31.8	26.4	14.2	6.5		
1.0	935	1381	-420	42.4	30.0	30.8	23.6	10.9	4.8		
0.5	510	812	-360	40.9	29.4	29.8	14.7	7.1	3.2		
0	0	244	-120	37.3	26.4	28.3	5.5	2.3	1.2		

F390-1-68

TEST NUMBER 29 DATE 3/8/66

SAMPLE DESCRIPTION Graded Ottawa Sand
0.0787" > Grain Size > 0.0165"

SAMPLE DENSITY: BEFORE LOADING $1.66 \ gm/cm^3$

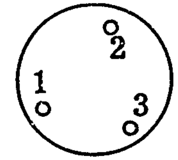
AFTER LOADING $1.68 \ gm/cm^3$

SAMPLE HEIGHT: BEFORE LOADING 4 inches

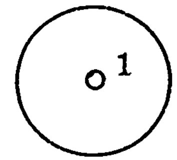
AFTER LOADING 3-15/16 inches

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING
2 inches

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0		
0.5	416	300	133	19.6	5.9	5.4	3.7	3.2	1.0		
1.0	896	660	228	26.6	7.8	7.2	6.1	6.6	1.9		
1.5	1360	990	342	31.0	9.0	8.3	8.1	9.6	2.9		
2.0	1888	1410	475	34.3	10.2	9.3	9.7	13.0	3.9		
2.5	2320	1725	570	36.8	11.1	10.2	11.6	15.1	4.9		
2.0	2048	1575	418	35.9	10.5	10.1	10.7	14.3	4.4		
1.5	1568	1350	190	35.4	10.1	9.8	10.2	12.9	3.9		
1.0	1056	990	38	34.3	9.7	9.3	9.4	10.2	3.2		
0.5	576	600	-48	32.1	9.0	9.1	7.9	6.6	2.3		
0	64	30	-38	26.3	9.0	8.8	1.6	3.7	0.5		

F390-1-68

TEST NUMBER 30 (Sheet 1 of 2) DATE 3/10/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787" > Grain Size > 0.0165"

SAMPLE DENSITY: BEFORE LOADING 1.60 gm/cm^3

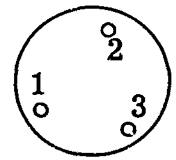
AFTER LOADING 1.63 gm/cm^3

SAMPLE HEIGHT: BEFORE LOADING 4-1/32 inches

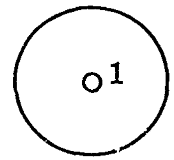
AFTER LOADING 3-31/32 inches

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS. Accidental application of 12.8 K-lb load at end of test.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0		
0.5	340	248	59	16.8	6.0	14.3	3.0	3.1	1.2		
1.0	748	620	238	27.8	8.0	21.2	5.2	6.6	2.7		
1.5	1275	930	404	31.2	9.5	27.0	7.4	10.1	4.3		
2.0	1700	1302	524	34.5	11.6	27.6	9.1	12.9	5.9		
2.5	2142	1643	666	36.8	13.0	29.4	10.6	15.8	7.3		
3.75	3400	2558	1000	43.1	16.6	34.7	14.8	22.4	11.6		
5.0	4675	3472	1357	46.2	19.7	37.6	18.5	28.5	15.6		
6.25	5780	4340	1666	49.1	22.5	39.8	22.4	34.6	19.3		
7.5	7140	5332	1975	51.9	25.4	43.6	27.1	41.2	23.5		
8.75	8262	6138	2321	53.3	27.2	45.4	30	45.2	27.1		
10.0	9588	7091	2618	55.5	29.2	47.6	34.2	50.9	31.4		
8.75	8432	7285	1368	59.4	31.5	49.4	34.6	52.5	33.0		
7.5	7293	6626	1142	58.4	31.0	48.8	32.1	49.7	31.1		
6.25	6120	5812	476	58.4	29.4	48.5	29.8	44.6	28.4		
5.0	4760	4960	119	55.5	28.9	47.7	25.6	39.9	25.1		

F390-1-68

TEST NUMBER 30 (Sheet 2 of 2) DATE 3/10/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

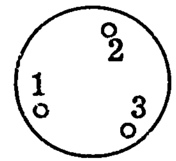
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

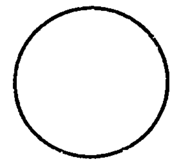
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
3.75	3570	3782	-178	54.8	27.7	46.2	22.1	34.1	21.2		
2.5	2295	2883	-333	52.9	26.3	45.1	17.7	27.1	15.6		
2.0	1785	2480	-416	52.3	26.0	44.7	16.8	23.6	15.1		
1.5	1360	1953	-428	51.4	25.5	43.2	14.9	19.6	12.6		
1.0	765	1395	-416	49.7	24.7	42.2	12.9	14.4	10.1		
0.5	340	852	-309	47.6	24.6	40.6	11.3	8.4	7.0		
0	-68	155	-190	43.8	25.3	38.2	6.3	0.9	1.8		
12.8	12580	9300	3380	60.9	33.9	50.9	43.5	63.7	41.1		

F390-1-68

TEST NUMBER 31 (Sheet 1 of 2) DATE 3/11/66

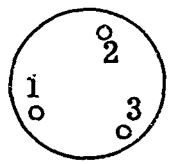
SAMPLE DESCRIPTION Graded Ottawa Sand
0.0787" > Grain Size > 0.0165"

SAMPLE DENSITY: BEFORE LOADING 1.74- gm/cm^3
AFTER LOADING 1.74+ gm/cm^3

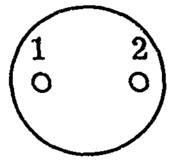
SAMPLE HEIGHT: BEFORE LOADING 4 inches
AFTER LOADING 3-63/64 inches

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING
2 inches

REMARKS: As load was being relaxed, load was decreased from 8.75 to 5.49 K-lb instead of 7.5 K-lb.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	DISPLACEMENTS LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	RADIAL LOADS TOP psi	BOTTOM psi	IMBEDDED GAGE LOADS NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	
0.5	422	316	164	6.6	3.6	3.0	6.0	3.3	1.1	1.8	
1.0	930	632	234	11.1	5.8	5.1	11.6	7.2	2.5	3.6	
1.5	1426	1027	410	14.4	7.7	6.9	16.8	10.8	3.8	5.4	
2.0	1927	1422	468	16.5	9.2	8.1	19.7	13.3	4.9	6.8	
2.5	2366	1833	585	18.3	9.7	9.1	23.5	16.0	6.2	8.4	
3.75	3634	2844	889	21.8	11.5	11.4	31.5	22.3	9.3	11.0	
5.0	4816	3792	1170	24.2	13.4	13.4	37.8	28.0	12.2	13.4	
6.25	6135	4708	1427	26.3	14.8	15.0	44.1	33.6	14.9	16.5	
7.5	7504	5688	1696	27.8	15.6	16.3	50.4	37.5	18.2	18.1	
8.75	8670	6636	2048	29.4	16.9	18.0	55.9	42.0	20.8	20.4	
10.0	10140	7821	2153	31.8	18.6	19.7	60.4	48.1	24.1	23.8	
8.75	8788	6920	1755	31.4	17.5	18.9	53.0	44.6	22.1	21.8	
5.49	5662	5372	410	29.2	16.8	17.4	50.4	37.5	18.2	18.1	
6.25	6084	5625	644	29.4	17.4	18	50.7	38.8	18.7	18.4	

TEST NUMBER 31 (Sheet 2 of 2) DATE 3/11/66

SAMPLE DESCRIPTION ______

SAMPLE DENSITY: BEFORE LOADING ______

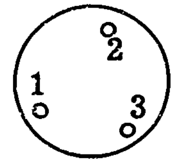
AFTER LOADING ______

SAMPLE HEIGHT: BEFORE LOADING ______

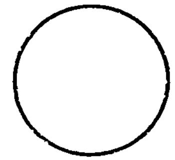
AFTER LOADING ______

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING ______

REMARKS: ______



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	DISPLACEMENTS LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	RADIAL LOADS TOP psi	BOTTOM psi	IMBEDDED GAGE LOADS NO. 1 psi	NO. 2 psi	NO. 3 psi
5.0	5002	5024	176	29.0	16.5	17.4	49.1	36.8	17.0	17.0	
3.75	3718	4108	-234	27.7	15.6	16.2	45.0	32.0	14.7	16.0	
2.5	2451	3128	-468	25.8	14.3	14.1	39.1	27.6	11.8	12.9	
2.0	1960	2623	-491	25.3	13.6	14.4	36.1	25.2	10.6	12.4	
1.5	1521	2180	-515	23.7	12.8	13.9	32.0	22.1	9.1	10.7	
1.0	980	1580	-445	20.8	11.9	13.1	27.1	18.4	7.4	9.2	
0.5	422	1011	-445	20.3	11.1	12.1	20.5	13.1	5.3	6.6	
0	0	316	-257	16.3	9.5	10.8	10.5	6.0	2.6	3.0	

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TEST NUMBER 32 (Sheet 1 of 2) DATE 3/15/66

SAMPLE DESCRIPTION Graded Ottawa Sand

See Remarks

SAMPLE DENSITY: BEFORE LOADING 1.65; 1.30; 1.67 gm/cm^3 by layer

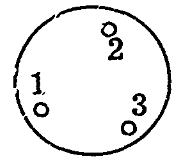
AFTER LOADING NC

SAMPLE HEIGHT: BEFORE LOADING 1/2"; 2-49/64"; 55/64; by layers

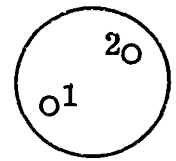
AFTER LOADING NR

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS: 1/2" dense Ottawa > 0.0165" on bottom; 2-49/64" fine Ottawa < 0.0165"; 55/64" loose Ottawa > 0.0165" on top.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	EF	0	EF	
0.5	406	250	178	46.8	23.7	43.6	3.1		2.5		
1.0	879	593	298	73.1	40.7	66.4	5.0		5.4		
1.5	1352	936	476	92.0	51.0	83.4	7.4		8.1		
2.0	1774	1248	595	103.6	59.7	93.7	8.6		10.8		
2.5	2298	1810	714	114.2	67.5	103.2	10.2		13.3		
3.75	3617	2527	1071	136.4	84.3	121.2	14.7		19.4		
5.0	4732	3432	1428	148.5	95.5	133.8	17.8		25.3		
6.25	6084	4446	1761	164.6	107.3	149.5	23.2		32.1		
7.5	7402	5304	2118	175.3	114.2	154.5	25.6		38.4		
8.75	8619	6318	2380	187.7	122.5	166.6	28.2		44.2		
10.0	10072	7160	2737	192.8	127.7	170.4	30.1		48.9		
8.75	8991	6786	2190	192.1	127.5	169.7	28.2		46.4		
7.5	7909	6131	1630	191.4	126.6	169.7	25.4		42.9		
6.25	6591	5569	1071	191.1	125.6	169.7	23.5	EF	39.1	EF	

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TEST NUMBER 32 (Sheet 2 of 2) DATE 3/15/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

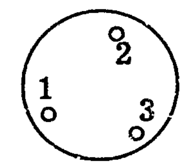
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

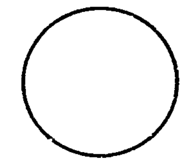
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	DISPLACEMENTS LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	RADIAL LOADS TOP psi	BOTTOM psi	IMBEDDED GAGE LOADS NO. 1 psi	NO. 2 psi	NO. 3 psi
5.0	5239	4680	898	189.9	124.6	168.2	22.1	EF	34.6	EF	
3.75	3988	3744	595	189.9	124.6	169.2	20.5		28.9		
2.5	2704	2730	262	188.5	123.5	166.6	17.3		22.6		
2.0	2197	2231	214	187.0	122.5	164.1	16.1		19.3		
1.5	1724	1872	[illegible]	186.3	122.5	163.6	15.8		15.8		
1.0	1268	1342	143	182.6	122.5	161.6	13.4		11.4		
0.5	676	842	95	175.3	121.4	159.1	10.8		5.7		
0	84	156	214	163.1	122.5	146.4	4.1	EF	-0.2	EF	

F390-1-68

TEST NUMBER 33 (Sheet 1 of 2) DATE 3/17/66

SAMPLE DESCRIPTION Ottawa Sand, see remarks

SAMPLE DENSITY: BEFORE LOADING See remarks

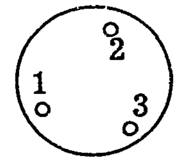
AFTER LOADING

SAMPLE HEIGHT BEFORE LOADING 3-7/8 inches total

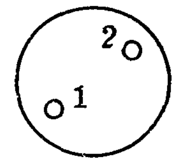
AFTER LOADING 3-11/16 inches total

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS: 21/32" layer at 1.7 density on bottom; 2-5/8" of 1.35 density in middle; 19/32" of 1.7 density on top.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOF psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	
0.5	414	316	176	38.5	18.0	34.3	4.2	2.6	3.0	2.4	
1.0	897	632	235	59.2	27.7	51.8	7.1	4.7	6.1	4.6	
1.5	1380	980	446	73.5	36.1	64.4	9.4	6.9	9.5	6.8	
2.0	1811	1343	517	83.3	42.2	71.7	11.6	8.5	12.7	9.0	
2.5	2329	1738	682	93.4	48.4	79.2	13.6	10.5	15.9	11.0	
3.75	3554	2623	975	109.1	62.3	93.0	17.8	14.2	23.9	16.5	
5.0	4796	3508	1292	121.8	72.1	102.5	22.2	18.1	31.6	21.7	
6.25	6141	4487	1622	133.4	82.0	112.1	26.5	21.8	39.4	27.3	
7.5	7348	5435	1880	139.3	88.9	119.7	30.4	25.4	47.5	32.5	
8.75	8720	6541	2232	148.1	96.2	126.2	34.0	28.5	54.5	37.6	
10.0	9867	7394	2526	154.9	102.4	132.3	37.3	31.5	61.1	42.4	
8.75	9039	6992	2056	154.9	99.6	132.3	35.2	29.8	58.0	39.9	
7.5	7762	6304	1434	154.4	99.0	131.3	32.1	27.6	53.4	37.0	
6.25	6452	5467	940	153.9	98.3	131.3	29.4	24.8	48.2	33.4	
5.0	5141	4661	517	152.9	97.6	130.3	25.6	21.7	41.8	29.3	

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TEST NUMBER 33 (Sheet 2 of 2) DATE 3/17/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

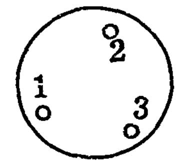
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

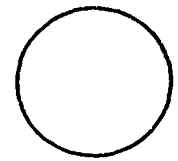
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
3.75	3795	3729	212	149.0	96.9	129.1	22.3	18.6	34.8	24.8	
2.5	2674	2781	-24	148.1	95.5	126.2	18.9	15.2	27.2	19.9	
2.0	2070	2449	-141	147.6	95.2	125.8	17.8	13.9	23.7	17.8	
1.5	1622	1896	-212	146.1	94.1	125.1	16.6	12.2	19.0	15.5	
1.0	1035	1343	-235	145.1	94.1	122.3	15.6	10.1	13.9	12.9	
0.5	604	853	-212	141.2	92.7	120.2	13.9	7.6	7.3	9.7	
0	34	158	-118	129.1	95.2	113.1	6.2	2.4	0.5	2.4	

F390-1-68

TEST NUMBER 34 (Sheet 1 of 2) DATE 3/21/67

SAMPLE DESCRIPTION Ottawa Sand, see remarks

SAMPLE DENSITY: BEFORE LOADING See remarks

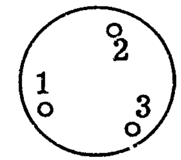
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING 3-15/16 inches total

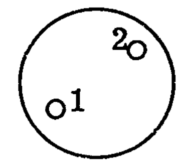
AFTER LOADING 3-25/32 inches total

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS: 9/16" layer at 1.61 density on bottom; 2-17/32" layer of fine < 0.0165" grain at 1.38 density in middle; 27/32" layer at 1.64 density on top.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	
0.5	406	278	180	40.6	22.1	34.1	1.3	0.9	1.4	2.2	
1.0	879	587	288	59.7	33.5	50.0	2.1	1.9	3.1	4.7	
1.5	1352	927	480	81.1	42.4	60.6	3.0	3.0	5.1	7.3	
2.0	1774	1236	600	81.8	49.1	67.7	3.7	3.9	6.8	10.0	
2.5	2332	1576	744	89.3	55.4	74.7	4.4	4.9	8.9	12.6	
3.75	3515	2503	1128	103.6	68.0	87.0	6.8	7.4	13.2	20.0	
5.0	4732	3399	1440	115.9	77.8	97.6	9.4	9.7	18.1	27.0	
6.25	6033	4326	1752	126.6	86.9	104.0	12.6	12.5	22.6	34.2	
7.5	7149	5222	2136	135.4	94.1	112.0	15.8	15.0	27.1	40.2	
8.75	8518	6141	2436	142.2	101.0	119.7	18.6	18.1	32.3	48.2	
10.0	9667	7092	2820	147.1	105.9	124.2	22.1	21.0	36.7	55.2	
8.75	8720	6628	2160	147.1	104.5	123.2	19.4	19.3	34.3	51.9	
7.5	7436	6026	1500	146.1	103.8	123.2	17.0	17.2	32.1	48.2	
6.25	6185	5253	984	146.1	103.8	122.7	14.7	14.8	28.7	43.1	
5.0	4969	4542	528	145.1	103.8	122.2	12.3	13.0	25.1	38.1	

TEST NUMBER 34 (Sheet 2 of 2) DATE 3/21/67

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

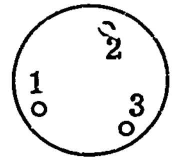
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

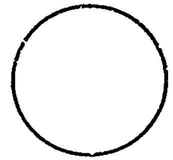
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
3.75	3786	3677	216	145.1	102.1	121.2	10.5	11.1	21.8	33.7	
2.5	2535	2750	-60	143.7	101.0	120.2	8.4	8.9	17.0	26.5	
2.0	2028	2240	-144	141.2	99.0	119.5	7.7	7.9	15.1	23.7	
1.5	1555	1854	-240	139.3	98.6	118.4	6.9	6.9	12.8	20.7	
1.0	1014	1313	-264	137.3	98.3	115.2	6.3	5.8	10.1	16.7	
0.5	575	865	-240	136.4	98.3	114.5	6.4	4.6	6.3	12.5	
0	30	247	-180	126.6	97.6	109.8	5.2	2.7	1.2	5.4	

F390-1-68

TEST NUMBER 35 (Sheet 1 of 2) DATE 3/24/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787" > Grain Size > 0.0165"

SAMPLE DENSITY: BEFORE LOADING 1.71 gm/cm^3

AFTER LOADING NC

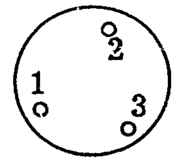
SAMPLE HEIGHT: BEFORE LOADING 4-1/16 inches

AFTER LOADING 3-15/16 inches

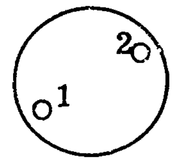
HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

2 inches

REMARKS: Teflon powder lubricant used.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	
0.5	424	325	0	29.8	20.6	24.5	0.2	0.7	5.2	4.9	
1.0	953	812	49	41.5	29.3	34.1	0.1	0.9	10.2	10.1	
1.5	1377	1300	61	49.7	36.3	41.2	0	1.1	14.4	15.0	
2.0	1800	1706	122	56.0	40.1	45.8	0.2	1.4	18.2	20.0	
2.5	2330	2210	182	59.7	44.3	49.2	0.3	1.7	21.7	24.3	
3.75	3530	3331	219	69.2	52.6	57.1	1.2	2.4	30.7	36.0	
5.0	4501	4306	243	74.3	55.0	61.9	1.6	2.9	36.4	44.2	
6.25	5913	5752	304	81.6	61.2	67.2	2.6	4.0	46.7	56.0	
7.5	7307	6947	413	87.3	66.2	72.1	3.7	4.9	54.2	67.8	
8.75	8525	8288	462	90.0	69.6	76.4	5.1	5.8	62.4	77.6	
10.0	9884	9620	510	94.8	73.2	79.2	6.3	6.9	70.4	86.8	
8.75	8684	8580	243	94.1	72.1	79.2	6.2	6.2	64.1	80.2	
7.5	7466	7434	182	92.5	71.6	77.8	6.0	5.7	59.0	73.6	
6.25	6072	6208	49	92.0	70.1	76.8	6.1	5.3	52.7	65.8	
5.0	4977	5168	0	90.6	68.5	76.3	5.5	5.2	45.8	57.4	

F390-1-68

TEST NUMBER 35 (Sheet 2 of 2) DATE 3/24/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

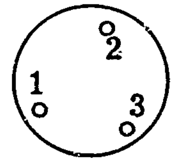
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

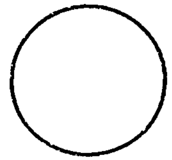
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
3.75	3706	3900	-24	88.9	67.5	75.8	5.2	4.6	38.8	47.9	
2.5	2436	2632	-36	87.7	67.0	75.2	4.2	3.9	30.2	37.1	
2.0	1942	2178	-49	87.2	65.9	74.2	3.7	3.5	25.8	32.9	
1.5	1412	1625	-36	86.7	63.8	72.2	3.2	3.1	21.9	27.1	
1.0	953	1138	-36	85.2	63.1	71.7	2.8	2.8	16.9	21.3	
0.5	424	618	-36	83.3	61.8	71.2	2.3	2.5	11.4	14.3	
0	0	98	-24	80.4	61.2	69.4	1.7	1.3	4.7	8.0	

F390-1-68

TEST NUMBER 36 (Sheet 1 of 2) DATE 3/29/67

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787" > Grain Size > 0.0165"

SAMPLE DENSITY: BEFORE LOADING 1.70 gm/cm^3

AFTER LOADING NC

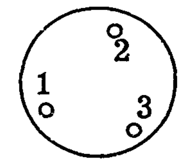
SAMPLE HEIGHT: BEFORE LOADING 3-15/16 inches

AFTER LOADING 3-13/16 inches

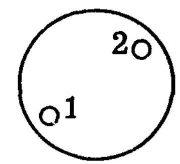
HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

2 inches

REMARKS: Teflon powder lubricant used



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	
0.5	424	342	118	26.9	14.6	18.4	0	0.3	4.4	2.5	
1.0	932	809	176	40.3	22.9	28.8	0	0.4	9.0	5.8	
1.5	1356	1244	212	48.7	29.3	36.4	0	0.6	13.5	9.9	
2.0	1864	1788	235	54.1	34.5	42.0	0	0.7	17.4	13.4	
2.5	2373	2239	235	58.9	39.0	45.4	0	0.9	21.4	17.8	
3.75	3644	3421	294	67.7	46.0	54.3	0	1.4	30.5	28.2	
5.0	5000	4665	400	73.1	52.2	60.6	0.3	2.1	39.1	38.8	
6.25	6272	5956	435	79.1	57.1	66.7	0.7	2.5	47.4	50.6	
7.5	7695	7184	470	82.8	61.8	71.2	1.1	3.3	55.2	58.5	
8.75	8797	8444	494	88.6	64.9	75.0	1.8	4.0	63.2	68.9	
10.0	10170	9703	588	92.0	68.0	77.3	2.1	4.6	70.4	78.9	
8.75	9017	8770	423	90.3	67.0	77.3	2.1	4.0	66.2	73.1	
7.5	7661	7588	235	89.3	65.9	75.8	2.2	3.6	61.5	64.4	
6.25	6483	6483	164	89.3	64.9	76.3	2.5	3.3	55.8	57.1	

F390-1-68

TEST NUMBER 36 (Sheet 2 of 2) DATE 3/29/67

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

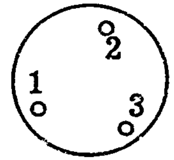
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

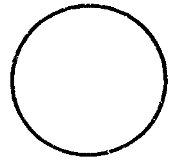
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
5.0	5170	5256	59	88.6	63.8	75.2	2.2	2.8	50.0	49.7	
3.75	3814	3965	0	88.0	62.3	74.5	2.1	2.3	43.0	39.4	
2.5	2627	2768	0	86.6	61.0	72.7	2.1	1.6	35.2	28.6	
2.0	2034	2208	-24	83.8	60.7	71.7	2.0	1.3	31.8	24.8	
1.5	1559	1773	-24	83.3	59.0	71.2	2.0	1.0	27.6	19.7	
1.0	1085	1275	-47	82.8	57.6	70.2	1.6	0.7	22.9	15.7	
0.5	508	653	-59	79.9	57.1	68.2	1.6	0.4	14.3	9.9	
0	34	249	-59	75.5	57.1	66.2	1.6	0.1	3.7	6.4	

F390-1-68

TEST NUMBER 37 DATE 3/31/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787" > Grain Size > 0.0165"

SAMPLE DENSITY: BEFORE LOADING 1.78 gm/cm^3

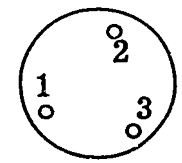
AFTER LOADING 1.81 gm/cm^3

SAMPLE HEIGHT: BEFORE LOADING 3-31/32 inches

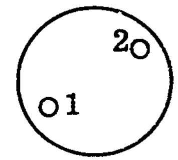
AFTER LOADING 3-15/16 inches

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS: Load applied smoothly rather than in steps.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	
2.5	2373	1576	774	38.9	15.6	22.0	16.3	10.5	3.4	3.3	
5.0	4746	3244	1547	48.8	20.2	27.3	24.9	21.9	7.2	7.5	
7.5	7458	5145	2285	50.0	23.8	30.6	33.6	33.4	11.4	12.2	
10.0	9967	6952	2927	54.1	26.8	33.3	42.0	43.8	15.7	16.2	
7.5	8678	5701	1571	52.9	26.5	33.0	40.4	38.8	13.2	14.0	
5.0	4949	4635	357	51.7	25.5	31.2	36.2	31.8	10.5	11.1	
2.5	2542	3013	-405	49.1	23.5	29.5	29.4	22.8	7.0	7.7	
0	170	464	-238	38.3	20.1	21.2	12.1	1.4	0.4	2.8	

F390-1-68

TEST NUMBER 38 DATE 4/1/66

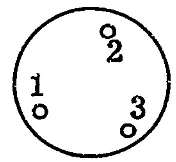
SAMPLE DESCRIPTION Graded Ottawa Sand
0.0787 inch > Grain Size > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING $1.70\ gm/cm^3$
AFTER LOADING NC

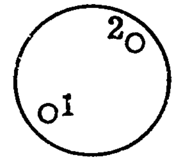
SAMPLE HEIGHT: BEFORE LOADING 4 inches
AFTER LOADING NR

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING
2 inches

REMARKS: Load applied smoothly rather than in step. Teflon powder lubricant used.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
0	0	0	0	0	0	0	0	0	0	0	
2.5	2369	2384	209	66.1	37.6	46.0	4.7	5.0	32.4	24.7	
5.0	4771	4647	290	83.2	52.4	62.9	7.4	EF	56.1	46.3	
7.5	7304	7152	418	94.1	62.3	73.5	11.2	EF	EF	68.4	
10.0	9936	9596	464	104.0	72.1	84.8	15.2	18.4	96.3	89.4	
7.5	7567	7569	209	102.3	71.6	83.4	13.4	15.4	83.7	77.3	
5.0	5067	5245	23	101.6	69.0	80.6	11.3	12.5	67.7	61.0	
2.5	2468	2742	-46	98.2	67.0	77.8	8.0	8.2	45.8	39.4	
0	66	298	-58	88.0	64.4	69.3	3.4	2.1	-0.6	10.5	

F390-1-38

TEST NUMBER 39 (Sheet 1 of 2) DATE 4/5/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787 inch > Grain Size > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING 1.58 gm/cm^3

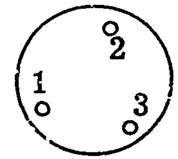
AFTER LOADING NC

SAMPLE HEIGHT: BEFORE LOADING 4-3/32 inches

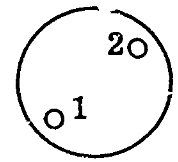
AFTER LOADING 3-7/8 inches

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS: Teflon powder lubricant used.



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	
0.5	425	373	47	42.7	20.3	33.9	0.7	1.2	2.4	5.1	
1.0	918	809	116	64.5	30.5	51.5	1.8	2.7	4.8	9.5	
1.5	1360	1244	163	81.3	40.8	64.6	1.7	3.5	7.4	14.7	
2.0	1802	1711	210	90.1	48.4	71.7	1.3	4.2	9.8	16.9	
2.5	2312	2177	233	99.5	57.1	77.8	1.3	4.8	12.6	23.7	
3.75	3485	3323	256	114.2	64.9	91.9	1.8	6.5	19.3	35.0	
5.0	4760	4416	408	125.6	67.5	99.0	1.9	8.1	25.7	44.7	
6.25	6052	5600	466	134.4	78.2	106.1	2.4	10.2	32.0	56.2	
7.5	7395	6998	524	139.3	84.4	111.1	3.2	12.0	39.1	68.4	
8.75	8568	7977	676	146.1	90.0	118.2	3.7	13.5	44.5	77.8	
10.0	9724	9330	722	149.0	94.1	121.2	4.5	15.7	51.0	87.6	
8.75	8840	8584	489	149.0	91.7	121.2	4.3	13.8	48.0	84.4	
7.5	7395	7114	396	148.5	92.0	120.2	4.5	12.9	42.1	74.2	
6.25	6273	6204	210	148.1	90.6	120.2	5.2	12.2	39.1	69.4	
5.0	4964	4976	70	147.1	90.0	119.2	5.5	11.2	32.9	61.9	
3.75	3740	3810	0	146.1	88.6	118.1	5.4	9.9	27.4	54.5	

F390-1-68

TEST NUMBER 39(Sheet 2 of 2) DATE 4/5/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

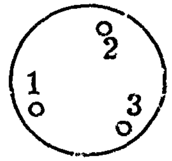
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

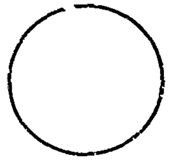
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
2.5	2465	2644	-23	145.1	86.5	115.2	5.4	8.1	20.3	44.2	
2.0	2006	2146	-47	144.2	86.5	114.5	5.2	7.4	17.1	39.7	
1.5	1530	1711	-47	143.2	84.8	113.8	5.1	6.5	13.8	34.7	
1.0	1020	1213	-58	139.3	83.7	113.2	5.0	5.3	9.6	28.2	
0.5	578	622	-58	137.3	84.4	112.4	5.4	3.9	4.8	21.8	
0	102	187	-23	132.5	87.2	109.6	4.9	2.2	0.5	8.9	

F390-1-63

TEST NUMBER 40(Sheet 1 of 2) DATE 4/7/66

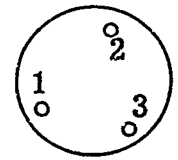
SAMPLE DESCRIPTION Graded Ottawa Sand
0.0787 inch > Grain Size > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING 1.56 gm/cm^3
AFTER LOADING NC

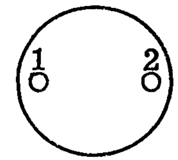
SAMPLE HEIGHT: BEFORE LOADING 4-1/8 inches
AFTER LOADING 3-29/32 inches

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING
2 inches

REMARKS: Teflon powder lubricant used



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0		
0.5	442	375	71	49.7	29.7	39.4	0.8	1.0	3.2	EF	
1.0	952	844	167	73.1	46.4	57.6	1.1	1.9	6.8		
1.5	1360	1250	214	89.3	57.6	70.7	1.3	2.8	10.3		
2.0	1938	1750	238	100.2	66.4	77.8	1.8	3.7	13.8		
2.5	2380	2188	262	107.7	73.2	85.6	2.1	4.5	17.2		
3.75	3655	3375	405	123.7	83.0	97.0	3.2	6.9	25.6		
5.0	4998	4609	476	134.4	92.7	107.1	5.0	9.7	33.9		
6.25	6120	5703	524	143.2	102.1	114.0	6.3	11.4	42.1		
7.5	7497	6938	666	147.1	103.8	121.2	7.8	13.8	50.3		
8.75	8670	8086	714	155.8	111.1	128.3	9.4	16.3	58.6		
10.0	10200	9375	857	158.8	114.2	131.3	10.9	18.9	66.6		
8.75	8840	8281	643	158.3	114.2	131.3	9.8	16.9	62.4		
7.5	7599	7312	452	157.8	114.2	131.3	9.3	15.4	57.7		
6.25	6324	6141	286	158.8	114.2	131.3	8.4	13.3	52.4		
5.0	5100	5062	214	156.8	114.2	131.3	7.5	12.2	47.9		
3.75	3740	3828	95	155.8	112.1	129.3	6.3	10.3	41.4	EF	

F390-1-68

TEST NUMBER 40(Sheet 2 of 2) DATE 4/7/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

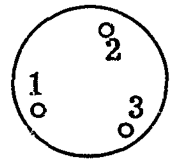
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

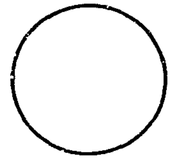
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
2.5	2550	2750	24	154.4	112.8	128.3	5.4	8.0	32.9	EF	
2.0	2040	2188	0	153.9	112.4	126.2	5.1	7.0	29.1		
1.5	1462	1656	0	152.9	114.4	124.2	4.5	5.9	24.4		
1.0	1020	1219	-24	149.0	110.7	123.2	4.2	4.8	19.3		
0.5	595	656	-24	147.1	110.7	122.2	3.4	3.3	12.5		
0	68	219	-24	144.2	110.7	120.2	2.1	1.4	2.6	EF	

F390-1-68

TEST NUMBER 41 (Sheet 1 of 2) DATE 4/11/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.078 inch > Grain Size > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING 1.79 gm/cm^3

AFTER LOADING NC

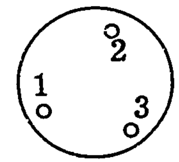
SAMPLE HEIGHT: BEFORE LOADING 4-5/64 inches

AFTER LOADING 4-1/16 inches

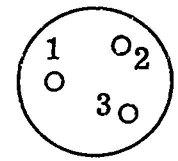
HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

2 inches

REMARKS: Teflon powder lubricant not used



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0		0	0	0	0
0.5	448	316	218	12.9	3.8	11	6.4	4.8	0.5	3.1	1.2
1.0	966	632	315	17.5	4.9	14.8	10.4	8.4	0.8	5.4	2.4
1.5	1449	948	508	20.6	5.7	17	13.5	12.2	1.3	7.7	3.6
2.0	1932	1296	678	22.5	6.4	18.6	15.9	14.9	1.9	14.3	4.8
2.5	2415	1643	799	24.4	7.1	20.1	18.9	17.5	2.5	EF	6
3.75	3726	2560	1210	27.8	8.6	23.4	24.6	24.2	3.9		9
5.0	4916	3476	1525	30.6	10.1	25.8	30.2	29.6	5.5		11.5
6.25	6244	4424	1936	32.7	11.2	27.8	36.3	34.9	7.2		14.1
7.5	7400	5214	2238	34.8	12.1	28.7	42.5	39.9	8.7		16.4
8.75	8746	6162	2602	35.9	13.3	30.3	47.9	44.6	10.4		19
10.0	10005	7110	2904	38	14	31.9	53.6	49.9	12.3		21.5
8.75	8970	6636	2226	37.7	13.8	31.7	50.4	48.3	11.4		20.1
7.5	7590	6115	1500	37.1	13.7	30.7	47.2	44.4	10.4		19.1
6.25	6348	5546	992	35.9	13.4	30.3	44.1	41.7	9.3		17.8
5.0	5141	4772	460	35.4	12.6	29.9	39.7	37.3	8.1	EF	15.3

F390-1-68

TEST NUMBER 41(Sheet 2 of 2) DATE 4/11/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

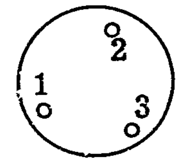
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

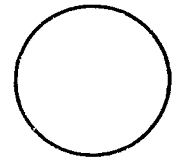
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS


GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
k-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
3.75	3795	3950	0	34.5	12.1	28.8	34.9	32.4	6.8	EF	13.7
2.5	2501	3065	-315	32.7	11.4	27.9	29.4	27.1	5.4		11.4
2.0	2036	2623	-460	31.6	11.2	27.1	26.8	24.5	4.5		10.1
1.5	1552	2212	-484	31	10.6	26.3	23.9	21.4	3.7		8.6
1.0	1035	1643	-484	29.4	10.4	25.2	20.8	18	2.9		6.8
0.5	586	1027	-460	27.5	9.9	25.5	16.8	13	1.9		4.7
0	104	506	-266	25.1	9.4	21.2	8.4	6.8	0.7	EF	2.3

F390-1-68

TEST NUMBER 42(Sheet 1 of 2) DATE 4/13/66

SAMPLE DESCRIPTION Dense Ottawa Sand

0.0787 inch > Grai Size > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING 1.79 gm/cm^3

AFTER LOADING

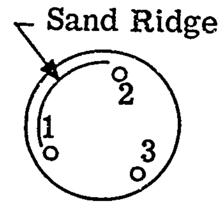
SAMPLE HEIGHT: BEFORE LOADING 4-3/16 inches

AFTER LOADING 4-5/32 inches

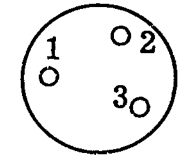
HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

2 inches

REMARKS: Very slight ridge of sand (after load applied) around edge of sample between LVDT locations No. 1 and No. 2



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	0
0.5	422	311	186	25.1	15.8	17.9	9.4	6.2	0.5	2.4	0.4
1.0	946	622	291	31.2	19.9	22	16	11.6	1.1	4.6	1.1
1.5	1420	964	489	35.1	22.5	24.7	22.4	17	1.7	6.6	1.9
2.0	1927	1322	606	37.3	24.4	26.5	26.9	21	2.5	8.4	2.5
2.5	2366	1679	699	38.6	26	28.3	32.1	24.7	3.1	9.9	3.3
3.75	3718	2566	1118	43	29.1	31.5	43.5	33.6	5	14.1	5.5
5.0	4986	3452	1445	45.3	31.7	33.6	51	41	6.8	17.7	7.6
6.25	6152	4354	1817	47.7	33.9	35.9	59.2	47.6	8.3	20.8	9.8
7.5	7605	5287	2120	49.2	36.3	37.9	68.8	53.9	10.3	24.4	12.2
8.75	8856	6158	2446	51.6	38.3	39.4	75.6	59.1	12	27.4	14.2
10.0	10140	7114	2796	53.6	40	41.2	83	66.7	13.9	30.7	17.2
8.75	8923	6648	2097	53.6	40	40.3	79.3	63	12.9	29.1	15.8
7.5	7909	6158	1421	52.6	39.4	40	77.2	60.9	12.3	27.4	14.5
6.25	6540	5520	885	52.1	38.8	39.4	73	57.2	11.1	25.5	12.6
5.0	5138	4727	373	50.4	38.1	38.8	68.2	52.5	9.9	23.5	10.9
3.75	3955	4012	-23	49.7	36.6	37.3	59.8	47.2	8.6	20.5	8.7

F390-1-68

TEST NUMBER 42 (Sheet 2 of 2) DATE 4/13/66

SAMPLE DESCRIPTION

SAMPLE DENSITY. BEFORE LOADING

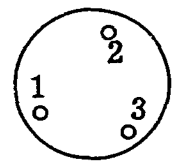
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

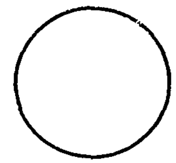
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
2.5	2636	3032	-396	47.6	35.4	35	51.3	39.9	6.8	17.1	6.2
2.0	2096	2550	-443	47	34.4	34.5	47.6	36.8	6.2	15.6	5.4
1.5	1690	2177	-489	46.5	33.7	33.9	43.3	32.2	5.2	14.1	4.3
1.0	1082	1586	-466	44.7	32.7	32.5	35.3	26.6	4.1	11.6	3.1
0.5	642	1011	-433	43.2	31.3	30.9	26	19.4	2.6	9	1.7
0	270	404	-233	40	29.8	28.8	14.2	9.6	1.1	5.4	0.5

F390-1-68

TEST NUMBER 43 (Sheet 1 of 2) DATE 4/19/66

SAMPLE DESCRIPTION Ottawa Sand

0.0787 inch > Grain Size > 0.0165 inch moist soil

SAMPLE DENSITY: BEFORE LOADING 0.0853 gm/cm^3 moist soil

AFTER LOADING NC

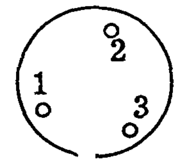
SAMPLE HEIGHT BEFORE LOADING 4-1/16 inch

AFTER LOADING 2-11/16 inch

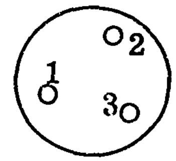
HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

2 inches

REMARKS: 7/16 inch Dense Ottawa sand on bottom sample; then 3-1/8 inch moist soil; finally 1/2 inch loose Ottawa sand on top of sample; moisture content of soil = 13 percent



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	0
0.5	385	325	119	305	353	302	1.3	1.3	4.1	2.5	2.5
1.0	805	618	238	455	500	420	3.2	2.8	7.9	5.1	5.4
1.5	1330	975	405	550	585	506	5	4.2	12	8.2	9
2.0	1785	1300	500	597	651	563	6.3	5.6	16.6	11.4	12.6
2.5	2345	1658	654	662	694	580	7.1	6.8	20.9	14.9	16.9
3.75	3570	2698	952	775	786	666	8.6	9.9	33.9	24.1	28.4
5.0	4830	3656	1190	813	852	720	9.8	13.1	47.9	34	40.6
6.25	6169	4648	1476	860	890	747	11.3	15.9	61.8	43.3	54.8
7.5	7350	5850	1761	927	923	768	13.5	19.4	80.2	54.2	70.4
8.75	8452	6728	1975	947	949	770	15	22.8	94.7	63.9	84.3
10.0	9870	7751	2261	990	972	797	16.8	25.9	114.4	74.3	98.1
8.75	8750	6971	1856	990	972	797	15.6	23.6	103.4	68.1	90.9
7.5	7700	6459	1380	990	972	797	14.7	21.5	97	61.7	84.3
6.25	6125	5525	785	990	972	797	12.9	19.2	88.9	52.9	73.4
5.0	4988	4794	476	990	969	788	11.8	16.9	78.9	45.5	63.6
3.75	3815	3868	190	968	965	776	10.4	14.6	67.3	35.3	51.8

F390-1-68

TEST NUMBER 43 (Sheet 2 of 2) DATE 4/19/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

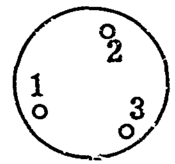
AFTER LOADING

SAMPLE HEIGHT. BEFORE LOADING

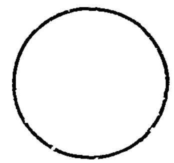
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in 0.001	in 0.001	psi	psi	psi	psi	psi
2.5	2520	2762	-48	968	964	776	8.5	11.4	52.5	25.8	38.8
2.0	2030	2275	-119	968	964	776	7.6	9.8	46	22.3	32.5
1.5	1488	1885	-214	968	964	776	7	8.6	39.4	18.6	26.5
1.0	1050	1365	-238	968	964	776	6	6.8	31.3	15	19.6
.5	525	812	-262	968	964	776	4.2	4.7	21.3	10.5	12
0	0	292	-262	968	962	770	2.1	2.8	7.6	3.2	2.8

Note: Soil compressed 3/8 inch during placement of piston before test began.

F390-1-68

TEST NUMBER 44 (Sheet 1 of 2) DATE 4/21/66

SAMPLE DESCRIPTION 1/2 inch Ottawa Sand; top & bottom 0.0787 > Grain 0.0165 inch moist Aberdeen soil (0.0787 > Grains) inch

SAMPLE DENSITY: BEFORE LOADING 1.77;0.858;202 gm/cm^3

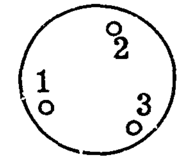
AFTER LOADING NC

SAMPLE HEIGHT. BEFORE LOADING 4-1/16 inches overall

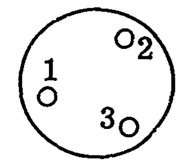
AFTER LOADING 2-3/4 inches overall

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS: 9/16 inch dense Ottawa sand on bottom; then 2-7/8 inch moist soil; 5/8 inch Ottawa on top moisture content of soil = 13 percent



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
0	0	0	0	0	0	0	0	0	0	0	0
0.5	422	286	186	358	318	260	1.3	1.4	4.3	1.8	2.9
1.0	915	604	302	505	444	408	4.4	3.1	8.5	3.6	6.0
1.5	1408	922	464	605	523	460	10.8	5.2	13.4	5.6	9.6
2.0	1830	1240	638	680	580	530	15	7.7	17.9	7.5	13.5
2.5	2394	1590	742	793	633	567	17.6	8.8	23	9.2	17.5
3.75	3608	2512	1114	937	714	640	22.5	13.2	37.3	14.4	29
5.0	4893	3403	1392	1000	767	665	25.2	17	52.5	19.5	41.8
6.25	6336	4452	1740	Offscale	817	710	28	20.6	72.1	25.5	56.3
7.5	7392	5295	2042		847	727	29.4	24.5	89.4	30.4	67.2
8.75	8800	6320	2320		879	746	31.3	27	110.5	36.7	83.6
10.0	9926	7203	2575		901	756	31.7	31	126.2	42.4	94.4
8.75	8976	6630	2204		901	756	30	28.6	118.4	39.4	87.9
7.5	7762	6106	1624		901	756	28.8	27.3	110.5	36.1	80.5
6.25	6442	5406	1114		899	756	27.3	24.3	101.8	33	69.8
5.0	5104	4532	650		899	756	25	20.6	88.4	28.4	58.5
3.75	3942	3752	278	Offscale	893	756	23.6	18.3	75.2	23.8	46.4

F390-1-68

TEST NUMBER 44 (Sheet 2 of 2) DATE 4/21/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

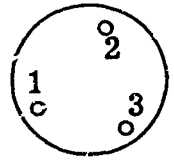
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

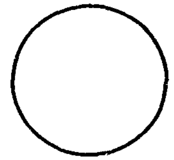
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
2.5	2640	2639	23	Offscale	897	756	21.3	13.8	58.5	19.3	31.2
2.0	2112	2258	-46		897	756	20.6	13	50.8	17.2	24.9
1.5	1690	1781	-70		897	746	19.7	11.2	42.6	15.5	18.3
1.0	1126	1304	-186		897	746	18.6	9	33.4	13.4	10.3
0.5	634	874	-232		897	746	15.8	7.4	21.5	10.8	2.5
0	70	286	-209	Offscale	895	746	6.3	3.9	6.6	5	-3.7

Note: Soil compressed 1/2 inch during placement of piston before test began

F 390-1-68

TEST NUMBER 45 (Sheet 1 of 2) DATE 5/2/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787 inch > Grain Size > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING 1.65 gm/cm^3

AFTER LOADING NC

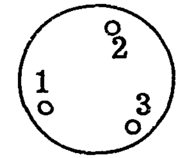
SAMPLE HEIGHT: BEFORE LOADING 4-1/16 inches

AFTER LOADING NR

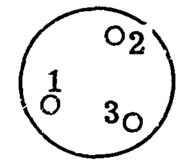
HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

2 inches

REMARKS: Teflon powder lubricant used



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	0
0.5	420	364	47	28.6	14.5	20	0.9	0.5	3.7	4.8	6.5
1.0	924	848	70	44.4	24.4	30.9	1.4	1.1	7.6	9	12.4
1.5	1344	1273	163	57.5	29.1	38.6	2.1	1.6	12.1	11.6	17.7
2.0	1764	1727	175	64.5	33.4	44.5	2.6	2.1	16.2	14.4	22.6
2.5	2285	2151	186	70.6	38.3	48.5	2.6	2.4	20.2	17.9	27.9
5.57	5376	5151	291	92	58.1	65.6	2.9	4.2	43.3	38.2	58.9
5.0											
6.25	5998	5818	350	95.4	61.8	70.2	2.1	4.4	47.4	42.1	64.2
7.5	7157	6908	396	100.9	66.4	74.2	2.4	5.1	56.3	50.3	75.2
8.75	8518	8181	443	104	71.1	77.3	2.8	5.9	65	58.6	87.8
10.0	9878	9575	489	109.1	74.2	80.8	3.2	6.8	74.3	66.6	100.6
8.75	8803	8636	350	108.4	72.7	80.8	3.2	6.2	69.6	61.9	93.1
7.5	7560	7499	233	107.7	72.1	80.8	3.3	5.6	63.8	55.2	83.6
6.25	6199	6272	163	107	71.6	79.8	3.3	5.2	55.1	48.8	73.6
5.0	5006	5075	70	105	70.1	79.3	3.7	4.8	48.6	41.8	63.3
3.75	3763	3939	23	103.6	68.2	77	4	4.4	40.7	34.9	53

F390-1-68

TEST NUMBER 4[illegible] (Sheet 2 of 2) DATE 5/2/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

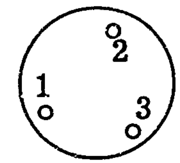
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

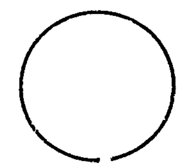
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
2.5	2587	2727	0	102.3	67	76.3	4.1	3.7	31.6	27.1	40.2
2.0	2016	2197	0	102.3	67	75.8	4.1	3.4	27.9	23.7	35
1.5	1428	1742	-23	100.9	65.9	74.5	4.3	2.8	22.3	21.3	28.4
1.0	1042	1212	-23	99.5	65.9	73.2	4.7	2.4	16.4	19.1	22.1
0.5	571	636	0	95.4	67	71.7	5.5	1.9	7.1	16.6	14
0	168	242	0	90.3	67.5	69.7	4.4	1.3	0.8	11.3	5.3

F390-1-68

TEST NUMBER 46 (Sheet 1 of 2) DATE 5/3/66

SAMPLE DESCRIPTION Graded Ottawa Sand

0.0787 > Grains > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING 1.67 gm/cm^3

AFTER LOADING NC

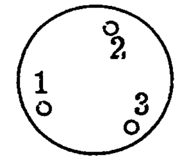
SAMPLE HEIGHT BEFORE LOADING 4-5/16 inches

AFTER LOADING 4-5/32 inches

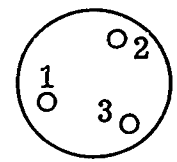
HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

2 inches

REMARKS: Teflon powder lubricant used



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	0
0.5	420	371	24	35.3	19.4	22.9	0.1	0.3	3.6	4	6.3
1.0	907	865	60	53.2	29.9	34.7	0.9	0.8	7.3	7.2	11.6
1.5	1344	1282	119	64.8	37.8	43.2	1.1	1.2	11.2	9.8	16.1
2.0	1764	1761	167	73.5	43.4	49.1	1.1	1.5	14.9	12.5	20.7
2.5	2318	2240	190	81.6	48.4	54.5	1.1	1.8	19.4	15.4	25.5
3.75	3444	3399	238	93.7	58.8	62.1	1.1	2.4	29.2	21.7	36
5.0	4754	4635	262	102.3	67.5	69.7	1.1	3.3	39.6	28.9	46
6.25	5914	5778	309	109.1	74	74.7	1.6	4.2	47.4	34.9	55.2
7.5	7207	6952	405	114.5	80.4	79.5	2.4	5.4	57.4	42.1	64.2
8.75	8568	8250	452	119.3	86.7	83.3	3.4	6.8	65.9	48.9	73.6
10.0	9946	9455	500	123.4	91.9	86.9	4.5	8	74.7	56	83.1
8.75	8870	8652	286	122.7	89.9	86.6	4.2	7.1	69.3	51.4	78.4
7.5	7560	7532	167	122.7	89	85.8	4	6.3	63.3	47.3	72.6
6.25	6174	6257	60	121.4	88.2	85.8	3.8	5.6	53.5	40	63.5
5.0	5116	5238	0	121	87.2	85.1	3.9	5.2	47.4	35.5	58
3.75	3864	4048	-48	119.3	84.6	84.3	3.9	4.5	38.7	28.9	48.6

TEST NUMBER 46 (Sheet 2 of 2) DATE 5/3/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

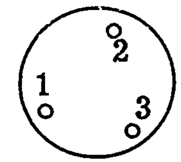
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

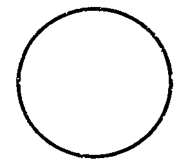
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
2.5	2654	2874	-60	116.9	83.6	82.3	4	3.9	29.2	23.5	39.4
2.0	2083	2287	-71	115.9	83	81.8	4.2	3.7	24.1	21.3	33.9
1.5	1613	1792	-71	114.5	83	80.8	4.9	3.3	18.8	19.3	28.4
1.0	1092	1236	-60	112.5	83	79.8	5.4	3.1	13.3	17.2	22.4
0.5	638	695	-48	109.1	83.8	78.3	5.6	2.5	6.4	14.4	14.4
0	235	232	0	103	84.6	75.8	3.9	1.3	0.7	8.4	3.7

F390-1-68

TEST NUMBER 47 (Sheet 1 of 2) DATE 5/6/66

SAMPLE DESCRIPTION Ottawa Sand

0.0787 > Grains > 0.0165 inch

SAMPLE DENSITY: BEFORE LOADING 1.76 gm/cm^3

AFTER LOADING 1.79 gm/cm^3

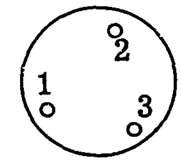
SAMPLE HEIGHT. BEFORE LOADING 4 inches

AFTER LOADING 3-5/16 inches

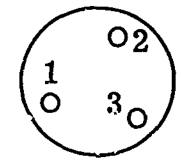
HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

2 inches

REMARKS: Ridge of sand (after load applied) around edge of sample between LVDT locations number 1 and number 2



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
0	0	0	0	0	0	0	0	0	0	0	0
0.5	406	242	212	18.3	7.8	8.4	5.5	2.4	1.1	0.3	1.1
1.0	930	545	400	26.3	11.2	12	7.4	5	2.5	0.6	2.4
1.5	1352	909	517	31.2	13.6	14	10	7.7	3.8	0.8	3.6
2.0	1791	1182	705	34.8	15.3	15.2	11.8	10.3	5.3	1.1	4.7
2.5	2298	1515	870	37.3	16.6	16.7	13.8	12.5	6.7	1.3	5.8
3.75	3549	2363	1222	41.5	19.5	19.4	18.9	18.4	10.1	2.2	8.6
5.0	4766	3212	1645	44.7	22.3	21.5	22.6	23	13.9	3	11.2
6.25	6084	4091	2044	47.5	24.6	23.2	28.2	28	17.6	4.2	13.8
7.5	7478	4878	2374	50.2	26.6	24.7	32.6	32.2	20.7	5.2	16.3
8.75	8746	5908	2773	52.6	28.9	26.5	37.2	36.8	24.5	6.3	18
10.0	10140	6772	3078	54.1	30.3	27.8	41.3	39.9	27.5	7.4	20.8
8.75	9126	6363	2538	53.6	29.4	27.7	40.2	38.8	26	6.9	20
7.5	7605	5318	1810	53.6	28.7	26.8	37.3	36.2	24.1	6.2	18.5
6.25	6490	5151	1198	52.6	27.7	26.5	34.2	33.9	22.3	5.6	17.4
5.0	5036	4469	646	50.6	26.8	26.1	31.5	29.9	19.2	4.8	15.7

F390-1-68

TEST NUMBER 47 (Sheet 2 of 2) DATE 5/6/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

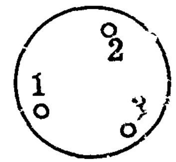
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

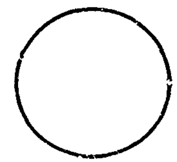
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS


GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
k-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
3.75	3718	3636	176	49.7	25.8	24.8	27.5	26.2	16.3	4.2	13.5
2.5	2434	2788	-235	47.6	24.4	23.8	23.2	21.5	12.8	3.3	11.1
2.0	1994	2424	-352	46.8	23.9	23.1	21.3	19.3	10.7	3	10.0
1.5	1453	2030	-446	45.9	23	22.6	18.9	16.5	8.9	2.6	8.9
1.0	1014	1515	-470	44.1	22.5	21.7	16.5	13.1	6.7	2.3	7.4
0.5	507	939	-446	41.6	21.8	20.8	13.1	8.6	3.8	1.8	5.3
0	135	515	-306	38	20.8	19.4	9.3	4.6	1.2	1.2	3

F390-1-68

TEST NUMBER 48 (Sheet 1 of 2) DATE 5/9/66

SAMPLE DESCRIPTION Ottawa Sand

(0.0787 inch > Grains > 0.0165 inch)

SAMPLE DENSITY: BEFORE LOADING 1.76 gm/cm^3

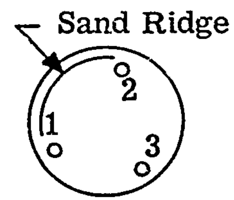
AFTER LOADING NC

SAMPLE HEIGHT: BEFORE LOADING 4-5/32 inches

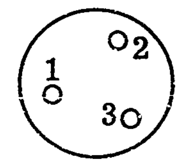
AFTER LOADING 4-3/32 inches

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS: Ridge of sand (after load applied) around edge of sample between LVDT Locations No. 1 and No. 2



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	DISPLACEMENTS LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	RADIAL LOADS TOP psi	BOTTOM psi	IMBEDDED GAGE LOADS NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	0
0.5	422	276	165	40.2	32.2	19.4	-4.5	-2.1	0	0.2	4.2
1.0	913	553	271	51.7	40.4	22.7	-6.3	-2.8	0	0.5	7.4
1.5	1352	860	472	62.1	46	24.8	-6.8	-3.1	0.1	1.0	10.3
2.0	1791	1151	590	67.7	50.5	26.3	-6.3	-2.4	0.2	1.5	13.2
2.5	2366	1504	732	72.1	53.6	26.9	-5.8	-1.9	0.6	2.2	15.8
3.75	3617	2241	1156	77.9	58.8	28.8	-4.4	-0.3	1.2	3.6	21.8
5.0	4833	3101	1581	82.8	62.3	30.7	-2.8	1.7	1.5	5.3	26.8
6.25	6084	3991	1935	85.7	65	32.3	-0.7	3.4	3.1	6.7	31.6
7.5	7453	4835	2360	88.6	67.5	33.9	1.4	5.5	4.2	8.3	36.8
8.75	8720	5772	2761	90.7	69.5	35.6	4.2	7.6	5.5	9.9	42.3
10.0	9937	6562	3068	93.7	71.6	36.4	6	8.9	6.3	11	45.3
8.75	8923	6309	2525	93.7	71.1	36.4	4.7	7.9	6	10.6	43.4
7.5	7658	5680	1723	93.4	68.8	35.8	3.3	6.8	5.4	9.8	40.9
6.25	6439	5127	1109	92	68.2	35.6	1.8	5.2	4.5	8.9	39.4
5.0	5104	4390	496	90.7	66.8	34.2	0	3.3	3.7	7.8	36.3

F390-1-68

TEST NUMBER 48 (Sheet 2 of 2) DATE 5/9/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

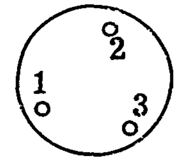
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

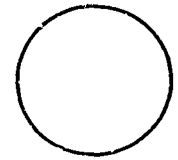
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS: MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	DISPLACEMENTS: LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	RADIAL LOADS: TOP psi	BOTTOM psi	IMBEDDED GAGE LOADS: NO. 1 psi	NO. 2 psi	NO. 3 psi
3.75	3786	3684	0	89.3	65.4	33.6	-1.6	1.7	2.8	6.6	31.8
2.5	2467	2763	-425	88.6	63.3	32.6	-3.2	-0.3	1.9	5	28
2.0	2028	2456	-472	87.3	63	32.1	-4	-0.8	1.4	4.4	25.1
1.5	1589	2057	-531	85.9	62.3	31.1	-5.1	-2.3	0.8	3.7	22.1
1.0	1014	1504	-519	82.5	59.9	30.6	-6.9	-3.9	0.4	2.6	18.4
0.5	439	860	-425	76.4	56.2	30.3	-9.1	-5.6	-0.1	1.1	10.9
0	0	230	-118	62.7	48.4	30.3	-7.9	-5.2	-0.4	0.2	2.9

F390-1-68

TEST NUMBER 49 (Sheet 1 of 2) DATE 5/13/66

SAMPLE DESCRIPTION Dense Graded Ottawa Sand

(0.0787 inch > Grains > 0.0165 inch)

SAMPLE DENSITY: BEFORE LOADING 1.824 gm/cm^3

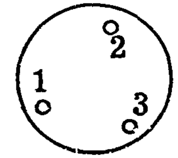
AFTER LOADING NC

SAMPLE HEIGHT: BEFORE LOADING 5-23/32 inches

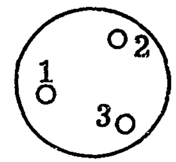
AFTER LOADING NR

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS: Teflon powder lubricant used



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
0	0	0	0	0	0	0	0	0	0	0	0
0.5	400	333	47	42.4	21.2	34.3	3.2	1.8	4.8	4.8	4.7
1.0	899	788	70	64.5	34.4	51.5	6.0	3.4	10.2	8.3	8.9
1.5	1322	1212	176	79.1	45	63.6	7.2	4.5	15.1	12.0	12.9
2.0	1765	1606	211	89.3	54.7	71.7	8.0	5.4	20.9	15.7	17.1
2.5	2298	2121	234	98.9	63.1	79.5	8.5	6.3	23.4	18.5	20.8
3.75	3430	3182	304	112.5	76.6	90.5	12.1	9.4	39.6	27.5	29.5
5.0	4729	4363	445	123.4	88.2	99.0	15.6	12.2	51.7	35.8	38.9
6.25	5927	5454	515	131.5	97.1	106.1	18.9	14.7	63.7	43.0	46.8
7.5	7243	6727	679	138.3	103.8	111.7	22.2	17.5	75.8	50.6	54.5
8.75	8442	7772	725	145.1	110.7	114.1	26.0	20.2	86.7	59.0	61.8
10.0	9923	9151	889	151.0	117.6	121.2	29.4	23.2	98.4	67.4	69.4
8.75	8824	8423	655	149	116.9	120.2	27.3	21.2	92.2	63.2	64.7
7.5	7592	7272	445	149	116.3	119.2	25.6	19.7	85.1	57.9	60.8
6.25	6444	6272	257	147.1	115.6	119.2	24.7	18.4	77.4	51.8	55.2
5.0	5062	5090	164	146.1	112.8	118.2	22.5	16.9	66.3	47.4	48.6

F390-1-68

TEST NUMBER 49 (Sheet 2 of 2) DATE 5/13/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

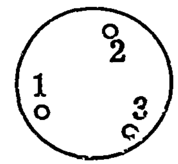
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

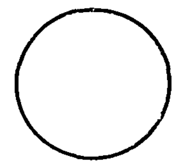
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
3.75	3863	3939	23	145.1	111.4	116.7	20.0	14.7	57.2	39.7	42.1
2.5	2597	2757	-47	143.2	110	114.5	16.7	12	44.3	31	33.5
2.0	2031	2272	-117	141.2	109	113.8	15	10.6	39.6	29.3	29.7
1.5	1598	1818	-140	139.3	108.6	113.1	13.5	9.1	31.9	25.7	25.1
1.0	1249	1273	-117	137.3	107.3	112.4	11.9	7.5	24.7	23.0	19.3
0.5	599	697	-70	134.4	108	109.6	10.2	5.3	13.1	19.1	11.8
0	167	242	-23	125.6	108	106.1	7.4	3.3	1.9	9.9	3.2

F390-1-68

TEST NUMBER 50 (Sheet 1 of 2) DATE 5/16/66

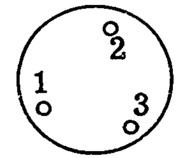
SAMPLE DESCRIPTION Dense Graded Ottawa Sand
(0.0787 inch > Grains > 0.0165 inch)

SAMPLE DENSITY: BEFORE LOADING 1.684 gm/cm^3
AFTER LOADING NC

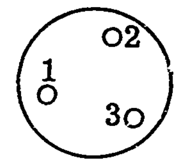
SAMPLE HEIGHT: BEFORE LOADING 5-13/16 inches
AFTER LOADING NR

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 4 inches

REMARKS: Teflon powder lubricant used



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	0
0.5	422	366	47	43.8	31.1	34.7	0.8	0.5	4.8	3.7	7.4
1.0	946	839	116	65.7	46	51.2	1.1	0.8	9.0	6.8	13.6
1.5	1386	1220	175	80.4	58.1	62.1	1.6	1.0	13.1	9.8	19.1
2.0	1927	1678	210	90.0	66.8	70.7	1.9	1.2	17	12.8	24.8
2.5	2400	2166	233	97.5	76.8	76.8	2.2	1.4	20.7	15.8	29.7
3.75	3634	3294	305	112.5	91.3	88.4	4.0	2.3	29.5	23.1	42.3
5.0	4833	4422	443	124.2	103.8	99.7	5.6	3.3	38.1	30.7	55.2
6.25	6135	5604	489	131.5	112.4	106.1	7.4	4.2	46.4	37	65.8
7.5	7504	6862	629	138.3	119.7	113.1	9.4	4.5	55.2	44.8	[illegible]
8.75	8746	8121	699	146.1	127.3	118.8	11.9	6.7	62	51.8	89.4
10.00	10,140	9272	816	149.0	132.2	123.2	14.4	7.8	69.3	58.2	96.7
8.75	8991	8540	606	149	132.9	123.2	12.7	6.8	65.0	53.9	90.7
7.5	7706	7320	419	148	131.5	120.9	11.8	6.3	60.2	49.3	85.2
6.25	6464	6268	256	147.1	130.8	120.2	11.2	5.7	54.2	44.5	77.8
5.0	5104	4972	140	146.1	129.8	118.8	10.2	5.2	47.4	39.1	68.9

E390-1-68

TEST NUMBER 50 (Sheet 2 of 2) DATE 5/16/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

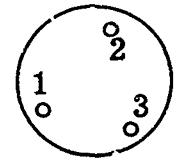
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

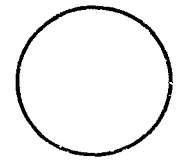
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
3.75	3819	3904	23	146.1	126.6	118.4	8.5	4.6	40.5	33.4	59.8
2.5	2603	2684	-23	144.2	124.6	115.2	7.4	3.7	31.4	25.5	47.9
2.0	2028	2196	-58	143.2	124.6	114.5	6.4	3.4	27.5	22.0	42.1
1.5	1606	1769	-70	140.3	123.2	114.5	6.1	3.0	22.7	19.1	36.2
1.0	1014	1220	-70	138.3	122.5	113.1	5.6	2.6	16.6	15.3	27.3
0.5	608	671	-70	136.4	122.5	111.7	5.4	2.1	9.2	13.2	17.9
0	169	244	-47	129.1	122.5	107.8	4.5	1.7	2.0	7.8	6.3

F390-1-68

TEST NUMBER 51 (Sheet 1 of 2) DATE 5/17/66

SAMPLE DESCRIPTION Graded Ottawa Sand

(0.0787 inch > Grains > 0.0165 inch)

SAMPLE DENSITY: BEFORE LOADING 1.69 gm/cm^3

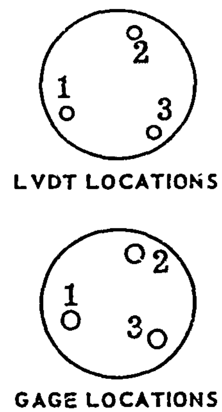
AFTER LOADING NR

SAMPLE HEIGHT: BEFORE LOADING 6-3/32 inches

AFTER LOADING NR

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS: Teflon powder lubricant used



SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	0
0.5	441	375	47	43.2	33.2	43	2.1	1.4	6	3.9	7.9
1.0	949	875	116	62.2	44.3	60.6	3.9	2.4	11.6	6.9	15.5
1.5	1390	1250	210	76.7	54.7	74.7	4.5	3	17.2	9.9	22.1
2.0	1864	1750	233	88.9	65.7	85.3	5.2	3.7	23.2	12.8	28.2
2.5	2373	2188	256	95.5	72.7	91.9	6.2	4.3	27.9	15.8	34.2
3.75	3644	3359	408	109.8	88.2	105.3	8.3	5.8	40.2	22.2	47.3
5.0	4915	4531	489	122.7	99.9	114.5	10.5	7.5	52.6	30.3	60.8
5.926	5763	5344	582	129.1	109.3	120.2	12.3	8.6	61.5	34	69.4
7.5	7500	6797	746	138.3	118.3	128	15.5	11.2	76.7	44.2	84.7
8.33	8238	7500	874	145.1	124.6	134.3	17.1	12.1	85.1	48.5	91
10.0	9967	8938	990	151.9	132.9	141.4	21.3	14.2	99	57.7	108.5
8.33	8339	7938	641	150	132.9	141.4	19.7	13.1	92.2	51.4	100.6
7.14	7068	6703	443	149	131.5	140.4	17.8	12.2	83.6	47.4	89.9
5.926	6000	5938	233	148	131.5	140.4	17.1	11.6	76.7	42.9	84.7
5.0	5085	5156	163	148	130.1	139.4	16.1	10.9	70.2	39.1	78.9

F390-1-68

TEST NUMBER 51 (Sheet 2 of 2) DATE 5/17/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

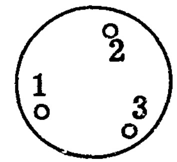
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

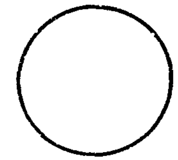
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
3.546	3627	3812	0	146.1	128	138.4	13.6	9.1	59.4	32.5	66.3
2.5	2610	2812	-47	145.1	125.3	134.3	12.3	8	48.9	26.9	56.2
2.0	2034	2281	-70	144.2	124.6	134.3	10.8	7.4	42.7	23.3	50
1.5	1593	1844	-116	143.2	124.6	133.3	10.5	6.7	37.1	20.8	43.4
1.0	1017	1312	-140	139.3	123.9	131.3	10.3	6	28.4	18.2	34.2
0.5	542	688	-140	136.4	123.2	129.3	8.4	4.4	17	14.5	20.8
0	254	344	-93	133.9	123.2	127.3	6.5	3	8	11	10.9

F390-1-68

TEST NUMBER 52 (Sheet 1 of 2) DATE 5/18/66

SAMPLE DESCRIPTION Graded Ottawa Sand

(0.0787 inch > Grains > 0.0165 inch)

SAMPLE DENSITY: BEFORE LOADING 1.69 gm/cm^3

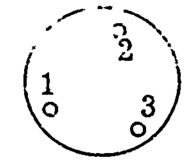
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING 6-3/32 inches

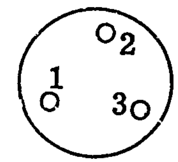
AFTER LOADING NR

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 4 inches

REMARKS: Teflon powder lubricant used



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS.

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
0	0	0	0	0	0	0	0	0	0	0	0
0.5	424	344	58	43.2	31	36.4	1.8	1.4	4.1	3.6	5.3
1.0	915	844	140	66.2	45.4	54.3	2.9	2.5	8.4	6.6	9.5
1.5	1356	1250	187	79.1	55.4	65.6	4.2	3.7	13	9.5	13.1
2.0	1864	1719	234	90.1	64	75.2	6	4.9	17.2	12	17
2.5	2339	2188	257	100.2	72.1	83.1	7.4	6.2	22.5	15.4	20.5
3.75	3526	3375	398	114.5	87.2	97.2	10.5	8.8	34	21.7	28.9
5.0	4780	4469	491	123.4	98.1	106.8	13.8	11.4	43.3	28.9	37.1
6.25	6000	5562	644	133.9	105.9	113.1	16.8	13.8	57.8	34.6	44.4
7.5	7170	6562	725	138.3	114.2	120.2	19.7	15.9	52.4	41 5	51.2
8.75	8644	7922	936	145.1	121.8	124.2	23.3	18.7	69.8	48.2	58.9
10.0	10,034	9000	994	149	128	131.3	26.8	21.2	80.5	54.8	67.3
8.75	8814	8125	725	149	128	131.3	25.2	20.2	76.1	50.6	62.1
7.5	7628	7266	515	148.5	128	131.3	23.6	19.2	72.4	47	57.1
6.25	6229	6094	292	148	125.9	129.3	22.5	18	63.9	42.1	50.8
5.0	5000	5031	211	146.1	124.6	128.8	20.5	16.3	56.8	36 1	43.7

TEST NUMBER 52 (Sheet 2 of 2) DATE 5/18/66

SAMPLE DESCRIPTION

SAMPLE DENSITY: BEFORE LOADING

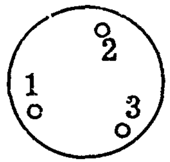
AFTER LOADING

SAMPLE HEIGHT: BEFORE LOADING

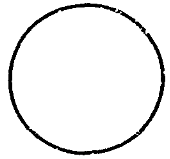
AFTER LOADING

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING

REMARKS:



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON	FIXED PISTON	CYLINDER	LVDT NO. 1	LVDT NO. 2	LVDT NO. 3	TOP	BOTTOM	NO. 1	NO. 2	NO. 3
K-lb	lb	lb	lb	in/0.001	in/0.001	in/0.001	psi	psi	psi	psi	psi
3.75	3797	4031	23	146.1	124.6	128.3	18.4	14.8	49.2	30.9	36.8
2.5	2610	2844	-23	144.2	122.8	123.7	15	11.8	40.2	24.9	27.6
2.0	2034	2344	-58	143.2	121.8	123.2	13.4	10.3	33.9	22.3	23.4
1.5	1593	1875	-117	141.2	119.7	122.2	11.6	8.8	28.8	19.6	18.9
1.0	1085	1312	-164	138.8	119.7	121.2	10	6.9	21.9	17	14
0.5	610	781	-140	136.4	119	119.2	7.6	4.7	13	13.5	8.4
0	102	281	-70	133.4	119	113.6	4.9	2.7	3.3	7.8	2.7

F390-1-68

TEST NUMBER 53 DATE 5/27/66

SAMPLE DESCRIPTION Graded Ottawa Sand

(0.0787 inch > Grain Size > 0.0165 inch)

SAMPLE DENSITY: BEFORE LOADING 1.78 gm/cm^3

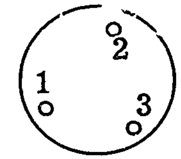
AFTER LOADING 1.79 gm/cm^3

SAMPLE HEIGHT: BEFORE LOADING 4-1/4 inches

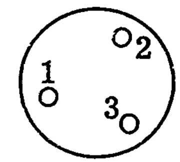
AFTER LOADING 4-7/32 inches

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS: Load applied by hyge shock tester



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
	0	0	0	0	0	0	0	0	0	0	0
	3181	2145	1305	EF	EF	EF	17.3	16.2	10.2	1.8	3.9

F390-1-68

TEST NUMBER 56 DATE 6/2/66

SAMPLE DESCRIPTION Graded Ottawa Sand

(0.0787 inch > Grain Size > 0.0165 inch)

SAMPLE DENSITY: BEFORE LOADING $1.69\ gm/cm^3$

AFTER LOADING NC

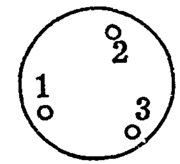
SAMPLE HEIGHT: BEFORE LOADING 6-7/32 inches

AFTER LOADING NR

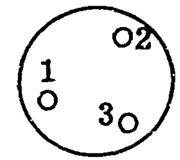
HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS: Teflon lubricating layer used

Load applied by hyge shock tester



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD K-lb	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
	0	0	0	0	0	0	0	0	0	0	0
	9900	7800	1900	109	135	121	2	7	15	15	20

F390-1-68

TEST NUMBER 57 DATE 6/3/67

SAMPLE DESCRIPTION Graded Ottawa Sand

(0.0787 inch > Grain Size > 0.0165 inch)

SAMPLE DENSITY: BEFORE LOADING $1.68\ gm/cm^3$

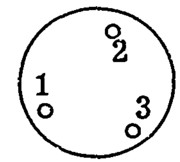
AFTER LOADING NC

SAMPLE HEIGHT BEFORE LOADING 6-1/8 inches

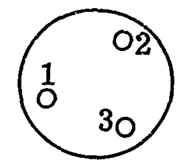
AFTER LOADING 5-15/16 inches

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS: Teflon lubricating layer used; load applied by hyge shock tester; first data line is peak loading, second line is steady state



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED

EF - EQUIPMENT FAILURE

NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
	0	0	0	0	0	0	0	0	0	0	0
	14,500	14,350	1360	144	155	133	Off	12.5	114.5	114.5	165.0
	5920	5200	468	138	150	129	Scale	0.7	44.5	43.4	70.5

F390-1-68

TEST NUMBER 58 DATE 6/3/66

SAMPLE DESCRIPTION Graded Ottawa Sand (0.0787 inch > Grain Size > 0.0165 inch)

SAMPLE DENSITY: BEFORE LOADING 1.78 gm/cm^3

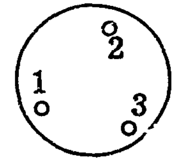
AFTER LOADING NR

SAMPLE HEIGHT: BEFORE LOADING 6-1/32 inches

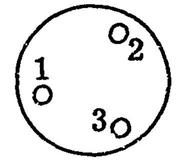
AFTER LOADING NR

HEIGHT OF IMBEDDED GAGES ABOVE BOTTOM OF SAMPLE BEFORE LOADING 2 inches

REMARKS: Load applied by hyge shock tester; first data line is peak loading, second line is steady state



LVDT LOCATIONS



GAGE LOCATIONS

SYMBOLS:

NR - NOT RECORDED
EF - EQUIPMENT FAILURE
NC - NOT CALCULABLE FROM DATA RECORDED

APPLIED LOAD	MEASURED AXIAL LOADS			DISPLACEMENTS			RADIAL LOADS		IMBEDDED GAGE LOADS		
K-lb	MOVING PISTON lb	FIXED PISTON lb	CYLINDER lb	LVDT NO. 1 in/0.001	LVDT NO. 2 in/0.001	LVDT NO. 3 in/0.001	TOP psi	BOTTOM psi	NO. 1 psi	NO. 2 psi	NO. 3 psi
	0	0	0	0	0	0	0	0	0	0	0
	15,300	10,950	5880	50	55	42	EF	60.4	65.0	33.5	52.6
	5590	4660	936	42	50	34	EF	33.0	25.0	11.3	22.0

F390-1-58